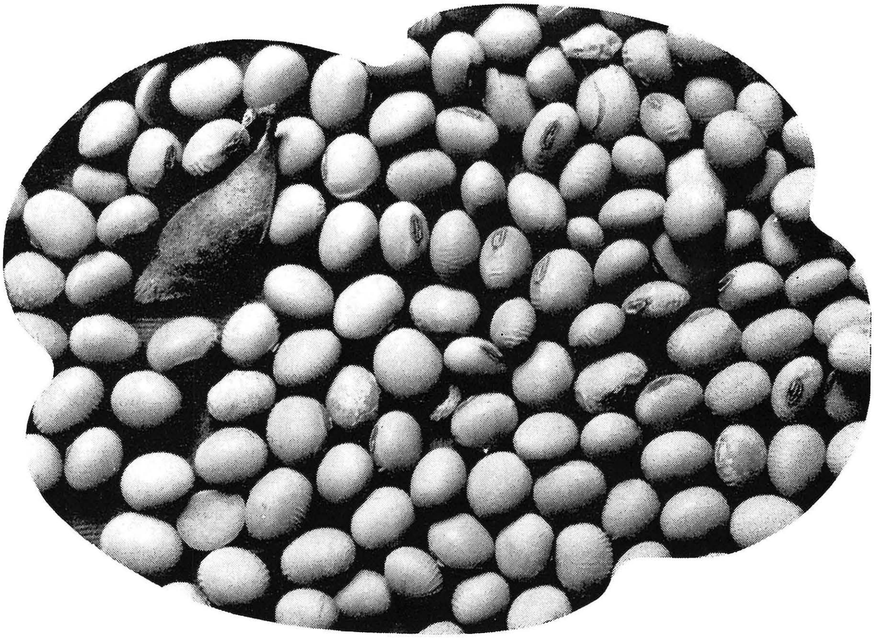

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Soybean Harvesting

---approaches to improved harvesting efficiencies

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CONTENTS

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SOYBEAN HARVESTING—
Approaches to Improved Harvesting Efficiencies

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INTRODUCTION

Growth in soybean acreage in United States closely parallels the population of combine-harvesters. Development of the combine-harvester gave the grower a more convenient and efficient method to harvest the crop (2). Even so, harvesting losses with the combine are generally reported to be 10 to 20 percent of the available crop (4, 6, 7). Loss of this magnitude is two to four times as great as harvesting losses reported for wheat and other small grains (3, 5).

Research was initiated in 1956 in an effort to determine methods for improving soybean harvesting efficiency. Specific objectives were to:

1. Determine nature and magnitude of losses
2. Study principles of operation and adjustment of conventional soybean harvesting equipment
3. Determine soybean characteristics significant to harvesting
4. Investigate the feasibility of harvesting at high moistures
5. Develop and evaluate design concepts which contribute to improved harvesting efficiency

This bulletin describes the methods and results of the research which terminated with the 1960 harvesting season.

METHODS AND CONDITIONS OF RESEARCH

Research Emphasis By Years

Effect of date of harvesting upon harvesting losses, bean yield and quality was the principal concern during the 1956 season. Twenty-four complete machine tests on each of five harvesting dates (and moistures) were made. Yields were recorded at four locations in rowed

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(40 inches) and drilled beans. Three replications were made at each location.

Also in 1956, an indication was obtained of problems which farmers experience in soybean harvesting. Performance tests were made of 29 farmer adjusted and operated combine-harvesters during the initial stage of the harvest. Procedures were similar to those described.

The effects of variety, various machine adjustments, and hour of harvesting were determined during the 1957 season. Each test condition was replicated three times or more.

Relationship of threshing aggressiveness to kernel damage and germination received major emphasis during 1958 season. Date of harvesting and machine adjustment tests were again conducted in 1959.

During the 1960 season, additional research evaluated the feasibility of early morning harvesting as a method for reducing harvesting losses and increasing acres per day harvested. Experimental reels were designed and partially evaluated. An automatic header control was installed and operated under field conditions.

Soybeans Used—Varieties, Planting Methods and Seasonal Variation

Presented in Table 1 is a description of the soybeans harvested during the research.

Kernel moisture at the nominal date of harvesting was very different for the different years of research (Figure 1). The patterns of moisture change during given years varied greatly and caused harvesting problems. A wet, cold summer during 1958 resulted in high moisture beans, even with delayed harvest. A dry, hot August accelerated the drying of beans during the 1959 season and caused the kernel moisture to drop below ten percent kernel moisture. The patterns of drying during 1956 (not shown), 1957 and 1960 seasons were similar.

In Figure 2, an indication of the relative length of growing season of the four varieties used in 1957 is presented. All varieties were planted the same day. The Monroe variety was used after the 1957 season because it could be harvested earlier than the other varieties.

Harvesting Machines and Years Used

In Table 2 certain specifications of the combine-harvesters used in the research are presented. Years when used are also shown. Machine C was modified to permit tailings collection. Except for selected reel and cutterbar modifications, the machines were operated with factory available equipment.

Table 1.—Variety, Planting Methods and Field Condition by Years

Item	1956	1957	1958	1959	1960
Variety	Harosoy and Hawkeye	Monroe, Harosoy Hawkeye and Lincoln	Monroe	Monroe	Monroe
Planting Method	Rowed and drilled	Monroe rowed and drilled; others drilled only	Rowed and drilled	Rowed and drilled	Rowed and drilled
Weed growth	Severe growth in certain areas in both rowed and drilled	Nil	Severe in drilled	Nil	Severe in drilled Some large weeds in rowed
Were defoliates used?	Yes	No	Yes	No	No
Typical potential yield, bushels per acre	28	34	36	22	39

Table 2.—Selected Chahacteristics of Combine Harvesters and Years Used

Characteristic Code letter	Combine-Harvester A	 B	 C	 D	 E
Type	P.T.O.	P.T.O.	S.P.	P.T.O.	S.P.
Gathering width, inches	74	72	120	84	126
Cylinder	rasp	rasp	rasp	rasp	rasp
Conveyor	canvas	canvas	auger	auger	auger
Straw rack	unit	walker	walker	unit	walker
Reel drive	power	ground	power	ground	power
Reel type	6 bat	6 tines	6 bat	6 bat	6 bat
Recleaner equipped	no	yes	yes	no	no
Pickup guards equipped	no	no	no	no	yes
Years used	1956	1956	1957-58	1959-60	1960

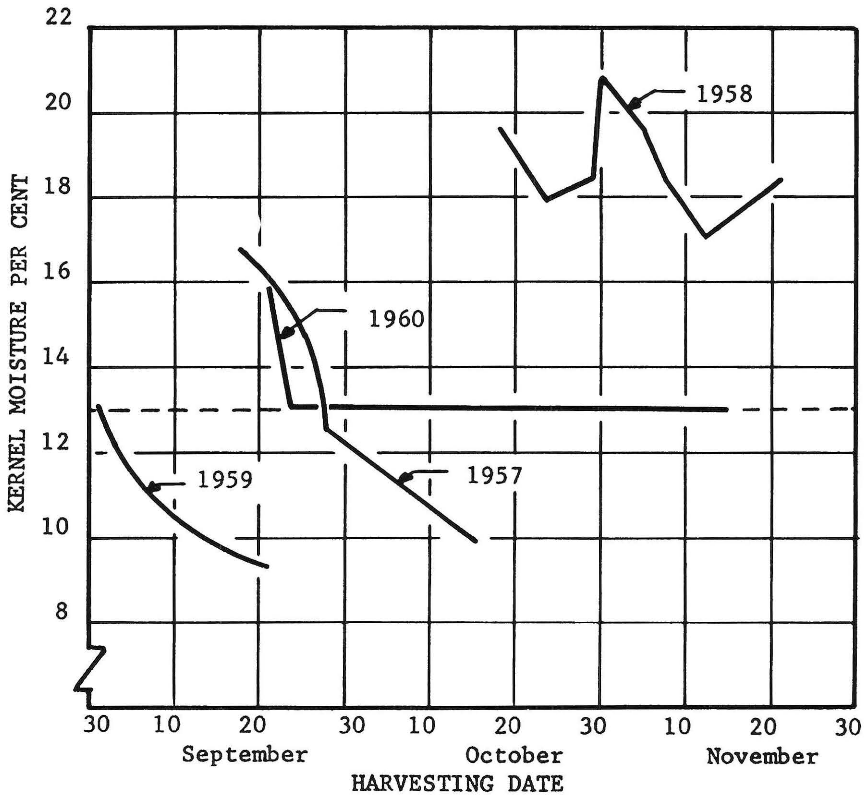


Fig. 1—Variations in kernel moisture by years.

Field Loss Determinations and Procedures

Techniques employed for evaluating cylinder, rack and shoe losses* were similar to those used by McCuen and Silver (5) and Johnson (3). Two canvases were positioned to separate and collect rack and shoe discharges. The machine was operated until the loads were stablized before collection was begun. Rack and shoe discharge was collected from 0.01 acres.

Discharges were processed using the rethresher developed by McCuen (5). After weighing, the rack discharge was passed over a rack mechanism to remove any free or loose beans which had not been previously separated (defined as rack loss). From the rack, the straw was fed into a double cylinder mechanism to remove any beans remaining in pods (cylinder loss). The shoe discharge was passed through the cylinder mechanism to thresh any pods. Loose beans and beans remaining in pods found in the shoe discharge comprised shoe loss.

Gathering losses were predicted from the ground area where rack and shoe discharges were collected. A wood frame, 40 by 78 inches and which enclosed 0.0005 acres, was randomly thrown within the test zone one or more times. The frame was oriented with the rows and adjusted laterally in rowed beans so that the row was centered. No area was used where a combine wheel had travelled over the stubble.

*See page 52 for definition.

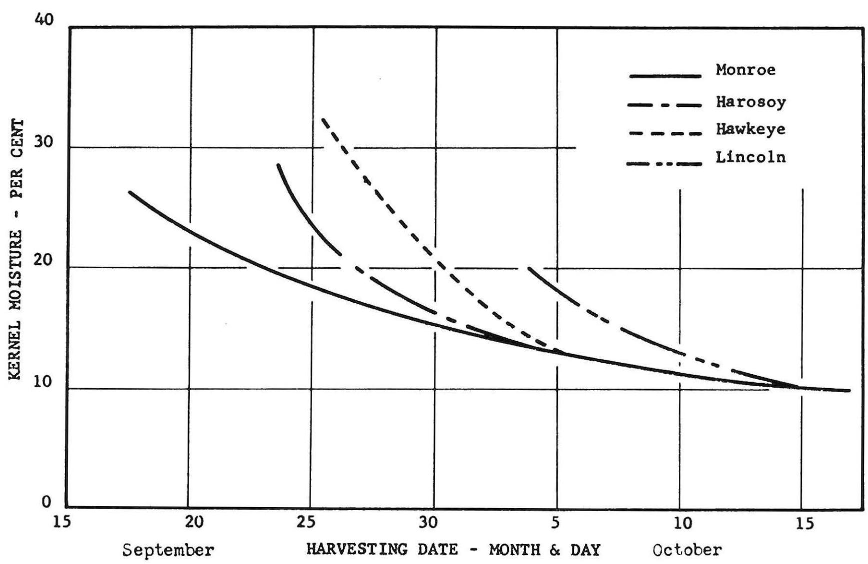
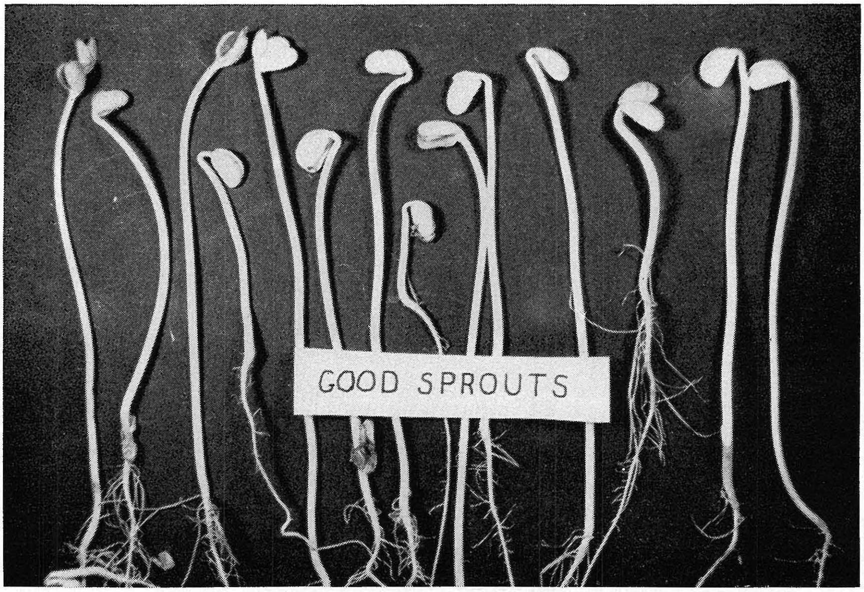
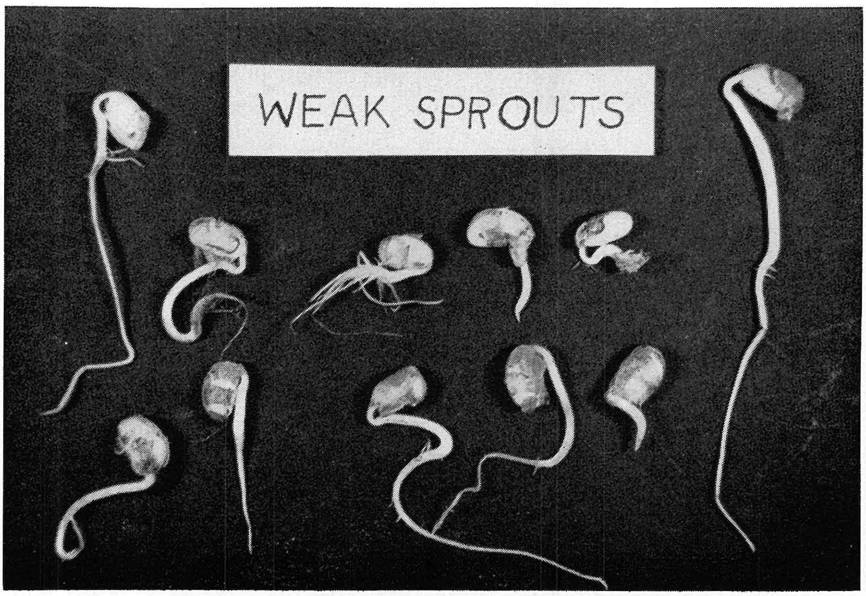


Fig. 2.—Variations in kernel moisture by variety (1957).



Germination tests were conducted as a measure of quality. Good and weak sprouts were determined for each condition as well as hard and dead beans.



All beans within the frame were counted in one of four groups: (1) beans lying free of pods or in detached pods on the ground (shattered loss), (2) beans remaining in pods which remained on the stubble (stubble loss), (3) beans remaining in pods on stalks which had been detached but for some reason not delivered into the harvester and (4) beans in pods on stalks which were lodged. Average weights of beans at 13 percent kernel moisture were used to convert the loss into pounds per acre.

Two methods were used to determine preharvest loss. During the first two years, the test plots were inspected before harvesting and beans lying on the ground were counted. Although generally satisfactory, this procedure did not account for grain which disappeared through consumption by wildlife. The second method corrected for this. Several areas adjacent to the harvesting area were identified and the disappearance of beans from the standing stalk determined. On the date of harvesting all opened pods were counted and removed from the stalk. On the final harvesting date, all remaining beans were counted and the result used to calculate the percent preharvest loss.

Stubble height was measured within the area used for gathering losses. Not less than six random measurements were recorded. Measurements were made to the nearest one-half inch.

Harvested yield (or tank yield) was collected from not less than 0.02 acres. The harvester was operated before and after each test until grain flow into the tank had ceased. At random, grain samples were collected and sealed in containers until moisture and other laboratory determinations were made.

When collected, the tailing discharge was taken from 0.01 acres by diverting the tailings into canvas sacks. Evaluation of tailings was performed in the laboratory.

Straw samples were placed in paper bags and weighed within 30 minutes after the test. Representative straw samples were selected, even if foreign material was present.

Laboratory Determinations and Procedures

Harvested grain was processed over a recleaner in order to remove foreign material. Test weight was determined before and after cleaning. All weights were made at field moistures.

Kernel moisture was determined by Steinlite or Brown-Duval moisture testers. Straw moistures were obtained by oven drying and weight methods.

Random samples of grain were sorted by hand to establish visual kernel damage. Splits, cracks and beans showing damage to the seed coat were all grouped as damaged. Percent damage was determined by weight. One-hundred-bean weights were determined from undamaged beans at room stabilized moistures.

Germination tests were conducted using the facilities of the Ohio Seed Improvement Association. Two replications, each comprising 4 groups of 25 beans, were germinated using the standard, rolled towel technique. Only whole, visually undamaged beans were used in the tests. All beans were permitted to dry at room temperatures before germination. Results were read as dead seeds, and weak and strong sprouts.

The tailings discharge, after weighing, was processed over a recleaner. Any beans remaining in pods were collected and threshed. Weights of unthreshed beans and unseparated beans were recorded.

Specialized Procedures

To permit a study of the effect of reel speed and adjustment upon shattered losses, a conventional four bat reel was mounted on a tractor (1). A variable speed, electric motor powered by a portable generator made it possible to obtain any desired reel speed. After operating the reel in previously undisturbed beans, shattered losses were counted from the ground.

During the 1956 season, an impact test was devised to relate mechanical shattering to moisture contents (1). Stems were sized and attached to a spring loaded arm. After impact, the threshed beans were collected and weighed. Unthreshed beans were removed by hand, and weighed. Grain at various stages of maturity, moisture content and surface moisture was subjected to the test.

Height of beans above the ground was established from standing stalks by stretching a string grid along the row. All beans in pods with point of attachment below the reference string were removed and counted in successive one inch increments. Six feet of row or more at any given location were used for the test.

RESULTS AND DISCUSSION OF RESULTS

Sources of Harvesting Loss

In Table 3, the sources and magnitude of harvesting losses when operating under typical harvesting conditions are presented. Harvesting efficiency varied from a high of 91.2 percent in 1956 to a low of 80.7 percent in 1959.

Table 3—Losses by Years When Harvesting Soybeans Under Dry Conditions (all losses in percent)

Year of harvesting Machine Variety	1956 (1) (2)	1956 A Harosoy Hawkeye	1956 B Harosoy Hawkeye	1957 C Monroe	1958 C Monroe	1959 D Monroe	1960 E Monroe
Kernel Moisture, % W. B.	13.2	14.4	13.9	12.6	18.5[4]	10.3	16.0
Potential yield, bushels per acre	28.0	26.4	26.4	33.9	26.5	21.0	41.8
Preharvest losses	T[3]	T	T	T	T	2.5	T
Gathering losses	7.0	6.8	9.5	11.9	13.9	15.2	12.5
Stubble	0.9	0.7	0.7	3.4	11.5	3.1	2.7
Stalk and lodged	2.7	1.4	4.0	2.3	11.5	3.1	4.2
Shattered	3.4	4.7	4.8	6.2	2.4	9.0	5.6
Threshing and separation total	3.0	2.0	4.1	1.0	N.C.[5]	1.6	0.2
Cylinder	2.1	1.6	1.3	0.3	N.C.[5]	0.5	T
Rack and Shoe	0.9	0.4	2.8	0.7	N.C.[5]	1.1	0.2
Total losses	10.0	8.8	13.6	12.9	N.C.[5]	19.3	12.7

(1) twenty-nine different farmer operated combines of various makes and models.
(2) various varieties
[3]trace
[4]moisture of beans did not go below 17 percent during normal harvesting period.
[5]not recorded

Cylinder, rack and shoe losses were generally very acceptable, although machine B was sensitive to rack and shoe losses. The higher cylinder speeds required for early season harvesting contributed to these losses in machine B through the increased energy imparted to the grain during threshing. A more positive curtain behind the cylinder reduced the losses.

Over 80 percent of all losses were gathering losses. Shattered loss was the largest individual source of gathering loss, being 55 percent of the total gathering loss. Stalk and lodged loss averaged 28 percent of gathering loss; stubble loss, 17 percent.

Preharvest losses were negligible when harvesting was completed before the kernel moisture dropped to ten percent. Only during the abnormally dry 1959 season did the beans dry below 10 percent kernel moisture and remain. During this period, preharvest losses averaged nearly one percent loss per day delay (Figure 3).

Losses which farmers experienced were very similar to those encountered with the research machines. The field study indicated that cylinder speed was inadequate on many machines. Cylinder losses averaged 0.56 bushels per acre. If harvest had been delayed another week to permit the beans to attain a more uniform moisture, the cylinder adjustments as used would have been adequate to eliminate the high cylinder loss.

Gathering Loss

Significantly improved soybean harvesting efficiency depends upon reducing the gathering loss. In the following, several factors which contribute to the losses are analyzed and discussed.

Theoretical Analysis

Shattered loss occurs when a force causes the pod to be opened and the bean freed before it is gathered into the harvesting machine. Two components of the harvester generally cause the loss—the reel and the cutterbar. As the reel enters into the grain, it disturbs the standing grain and can displace it vertically and laterally. As the bat makes initial contact with the grain, impact forces result. Magnitude of these

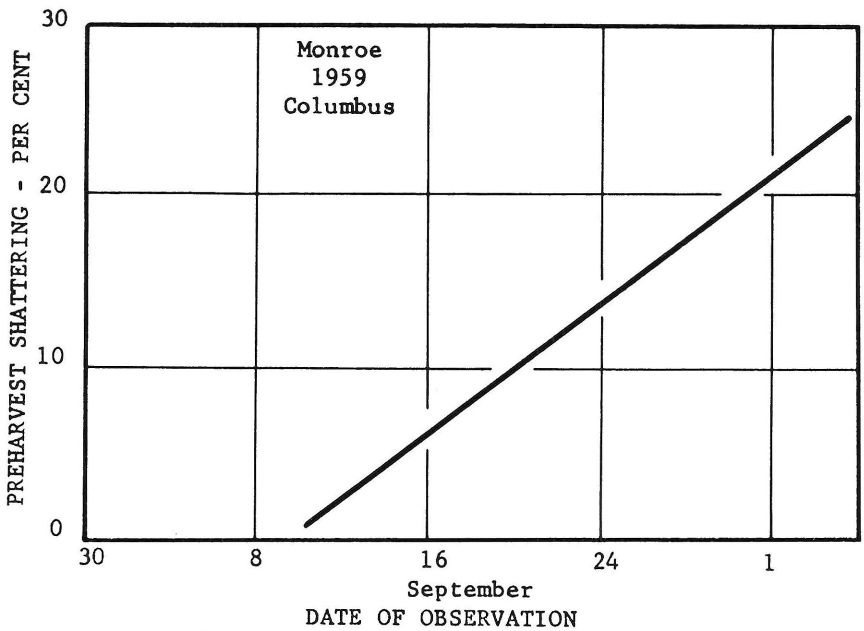


Fig. 3—Preharvest loss during the 1959 season.

impact forces and the displacement of the grain depend upon the reel index, reel adjustment and bat peripheral speed.

Absolute path of the bat of a reel relative to grain depends upon the reel radius, depth of penetration of bat into the grain and the reel index. Figure 4 shows the path of the leading edge of a six radial-bat-type reel indexes of 1.25, 1.5, 1.75 and 2.0. Greater stalk displacement and agitation occur as the reel index increases (at constant forward speed, increased reel rpm increases the reel index). For down or lodged grain, the greater stalk displacement may be desired but the increased agitation will increase shattered loss.

Reels designed to permit the bat to remain parallel to standing grain make less contact with it during entry. Path of the bat remains

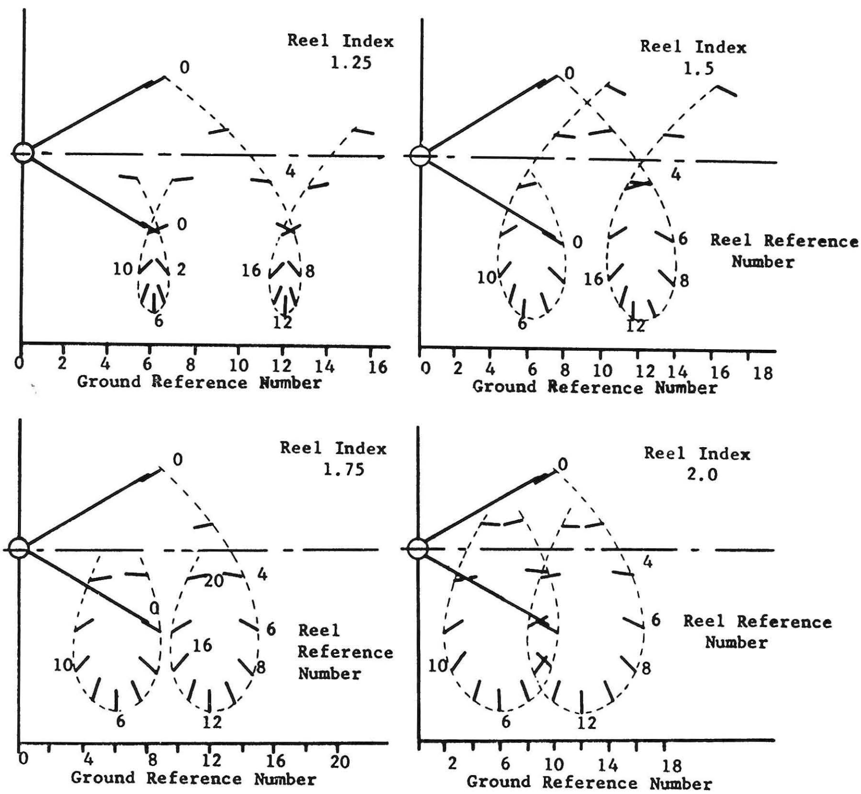
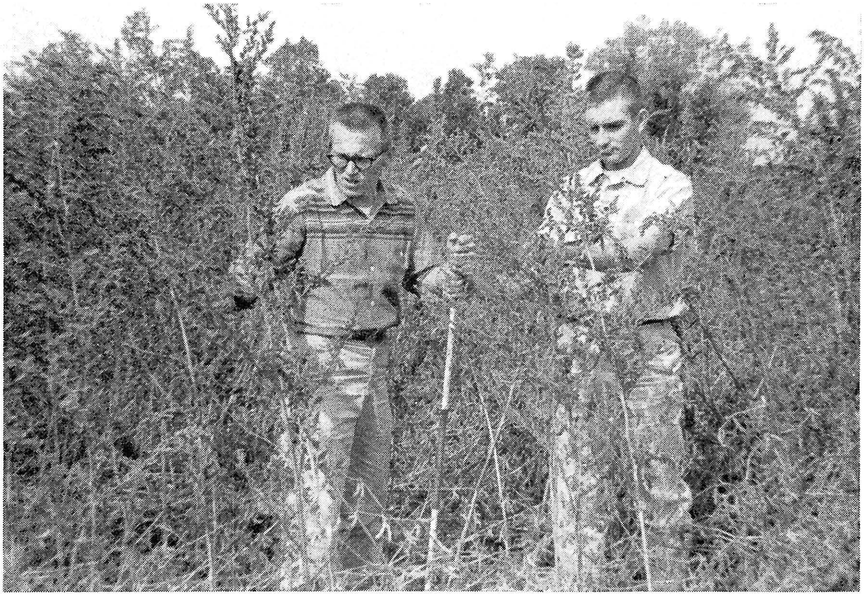


Fig. 4—Displacement of reel bat relative to the ground. (Reference numbers indicate reel position for any corresponding ground position).

very similar, however, and the same relative displacement occurs. A reel with tines has the least direct contact with the grain.

The cutterbar can cause shattered loss also by (1) direct cutting of pods located in the cutting zone, (2) compressing two or more stalks together during the cuttting process which threshes out some beans and (3) by stripping pods from the stalk as the stalk slips along the knife section prior to cutting. With present design of cutterbars, direct cutting of pods within the cutting zone can not be avoided. The amount of stalk bunching and stripping before and during cutting depends upon the cutting index and the geometry of the knife and ledger plate.

In Figure 5, the absolute motion of a point on the cutting edge of a knife section with the ground is shown for two cutting indexes (guard and knife spacing is three inches). The maximum probable stalk displacement before cutting is shown for the two conditions. At high cutting indexes (high knife speed and low ground speed) the maximum displacement depends upon ledger plate spacing and generally is minor. At low cutting indexes (obtained through high ground speeds), the theoretical stalk displacement may be several inches. If the stalk does not break, it must slide along the knife section until in a position



Weed growth was a major problem during certain years. Beans shown were drilled.

to be cut. Any pods in the sliding zone would be stripped. Maximum stalk slippage depends upon cutterbar height above the ground and cutting index as shown in Figue 6.

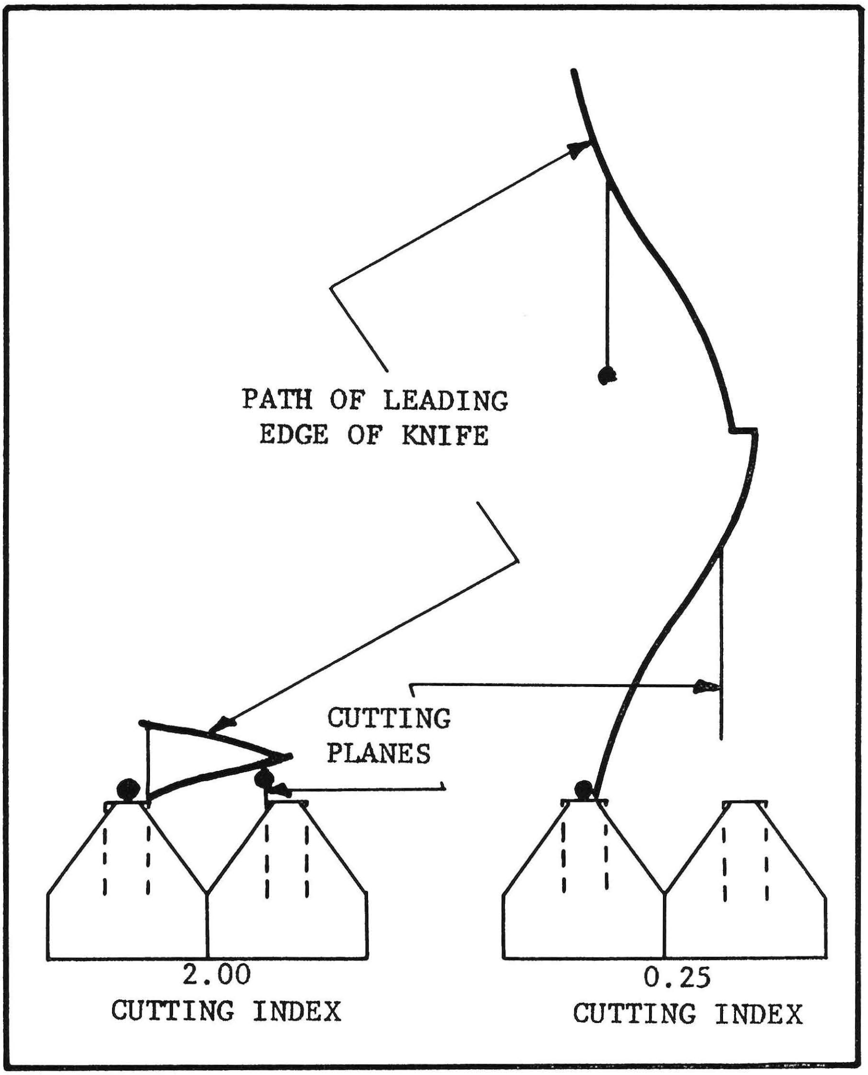


Fig. 5—Horizontal displacement of leading edge of knife relative to the ground. (Dots indicate maximum stalk displacement).

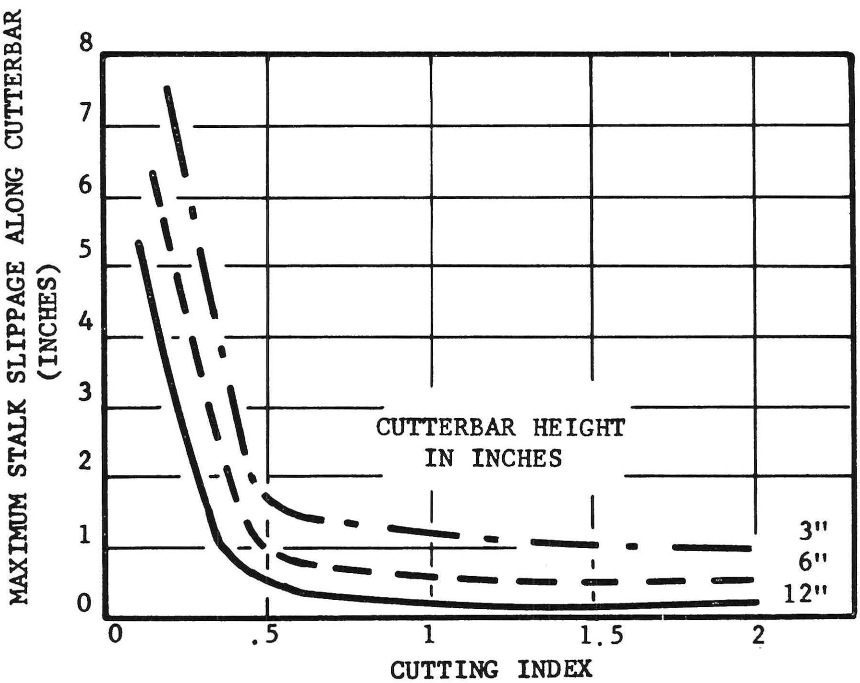


Fig. 6—Maximum stalk slippage at various cutting indexes and heights of cut.

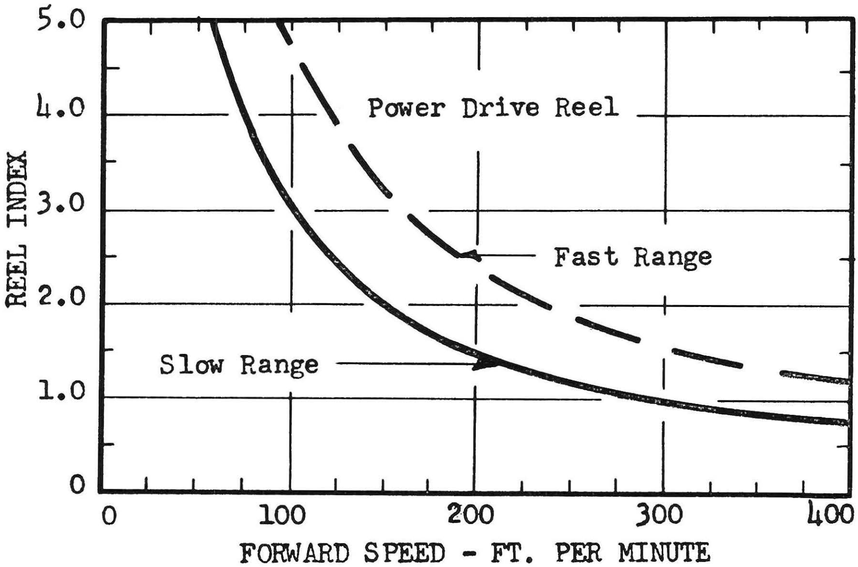


Fig. 7—Effect of ground speed upon reel index (constant reel rpm).

Figures 7 and 8 present the effect of ground speed upon reel and cutting indexes. A ground driven reel maintains a constant reel index (same absolute path between bat and grain at all speeds); however, the resulting impact forces increase at the higher ground speeds. The reel index changes with speed on a power driven reel, but the impact forces remain nearly the same. The range of reel indexes using a self-propelled combine will be large, since ground speed can be varied through a wide range, independently of reel speed.

Conventional design fixes knife speed as a function of the basic power source of the harvester. Therefore, a considerable range in cutting indexes is possible with all machines.

Stubble loss depends upon characteristics of the plant and height of cut. Characteristics of the plant are discussed in the next section. Height of cut is determined by the vertical positioning of the cutterbar and by the cutting index.

Stalk losses occur whenever the cut material is not delivered back into the conveying mechanism. Frequently, stalks are caught by a bat, carried over the reel top and dropped to the ground. Also, if the cut stalks are not promptly delivered to the conveyor, the stalk can drop toward the ground and be cut again, with a short piece of stalk being missed. Proper adjustment of reel (both position and speed) can

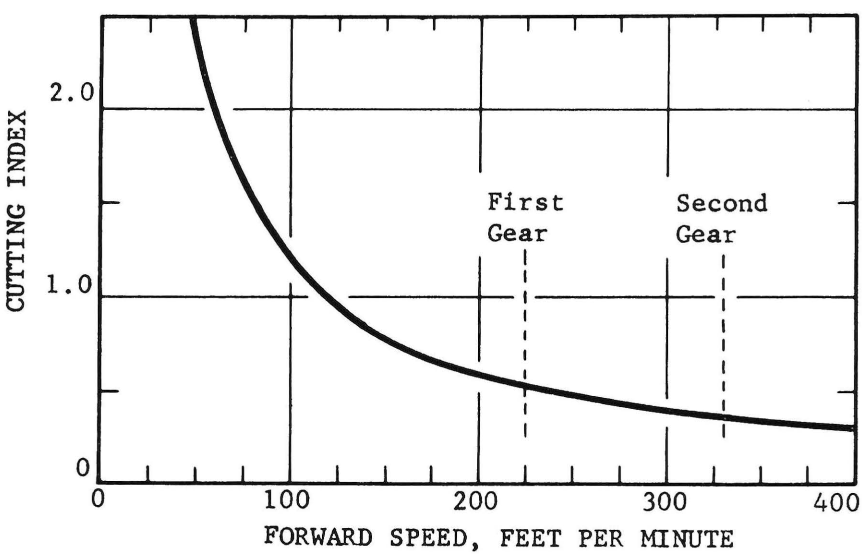


Fig. 8—Effect of ground speed upon cutting index (constant knife speed).

minimize this stalk loss. Lodging losses are likewise influenced by reel adjustment. Greater horizontal bat displacement relative to the ground is desirable in lodged grain. This can be obtained using higher reel indexes.

Plant Factors Influencing Gathering Losses

Principal plant factors influencing gathering losses are ease of shattering, height and distribution of pods relative to the ground and susceptibility to lodging.

A relationship between shattering and kernel moisture content is presented in Figure 9. The results were obtained with Lincoln and Hawkeye beans. Shattering refers to mechanical rather than natural shattering. Within the limits of this study, mechanical shattering was independent of variety.

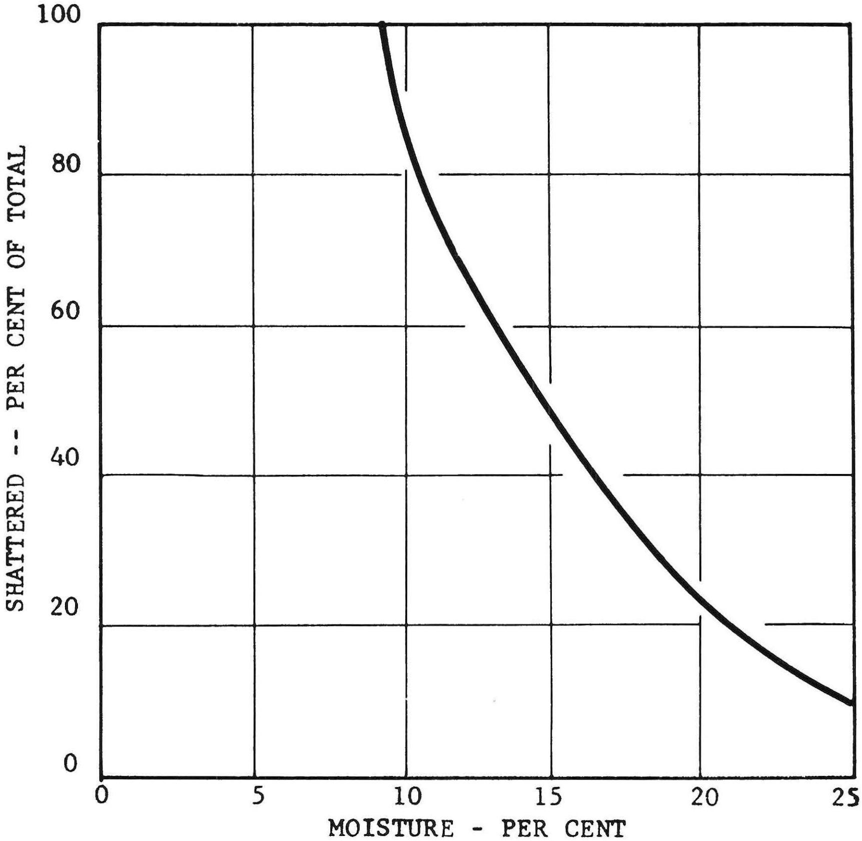


Fig. 9—Relationship between percent of beans mechanically shattered and kernel moisture.

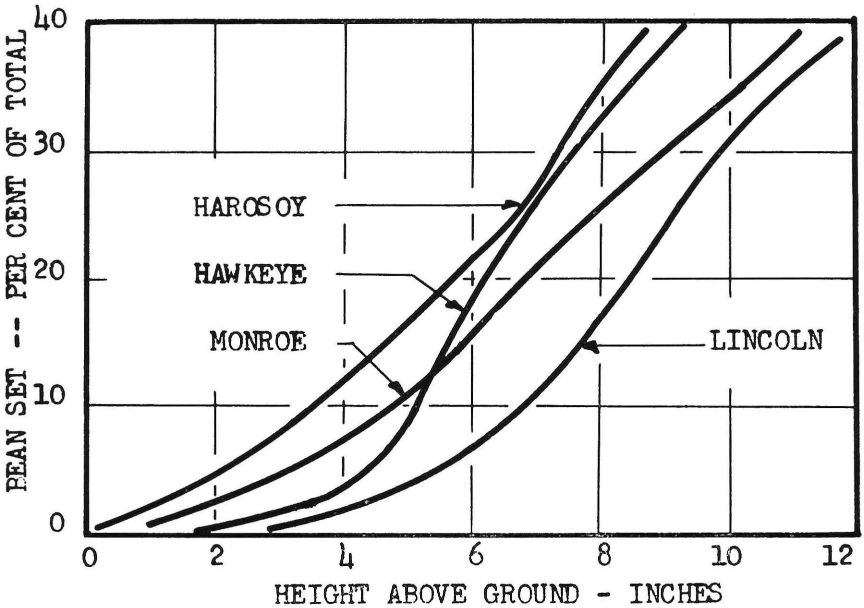


Fig. 10—Distribution of beans versus height above the ground for different varieties.

Height and distribution of beans relative to the ground varies with variety and planting method. Typical curves displaying the height above ground to percent of total set are presented in Figure 10 for four varieties. With a four inch cutting height, the expected stubble loss in Harosoy would be five or more times that of Lincoln. Beans per inch of height are plotted in Figure 11. When cutting at heights less than five inches, direct cutting of beans as a cause of shattered loss will be minor.

Planting method influences the location of pods as is apparent from Figure 12. Stubble loss at a cutting height of four inches would be expected to be less than 0.5 percent.

Lodging as related to variety was not studied in this research.

Machine Adjustments and Operation Influencing Gathering Loss

The importance of proper reel speed and adjustment can be determined from Figures 13, 14, and 15. In Figure 13 shattered loss caused by the reel is shown plotted against reel index. Since combine ground speed was nearly constant at 2.75 mph, the reel rpm increased directly with reel index. Operation with the reel index at 1.25 will generally yield minimum overall gathering losses.

Figure 14 is applicable to a harvester with a ground driven reel (reel index 1.07). Doubling forward speed, doubles reel rpm and results in twice the shattered loss caused by the reel.

The effect of vertical adjustment of the reel upon shattered losses is presented in Figure 15 for standing beans. In lodged beans, the curves would not apply. Positioning the reel lower than that required to gain control of the stalks will greatly increase shattered loss.

A balance must be attained between shattered loss, stalk and lodged losses. In general, the reel should be adjusted for minimum shattered loss in standing beans and minimum lodged loss in lodged beans. This would necessitate a rapid change adjustment to vary reel speed and height under many harvesting condition, since lodging is generally not uniform.

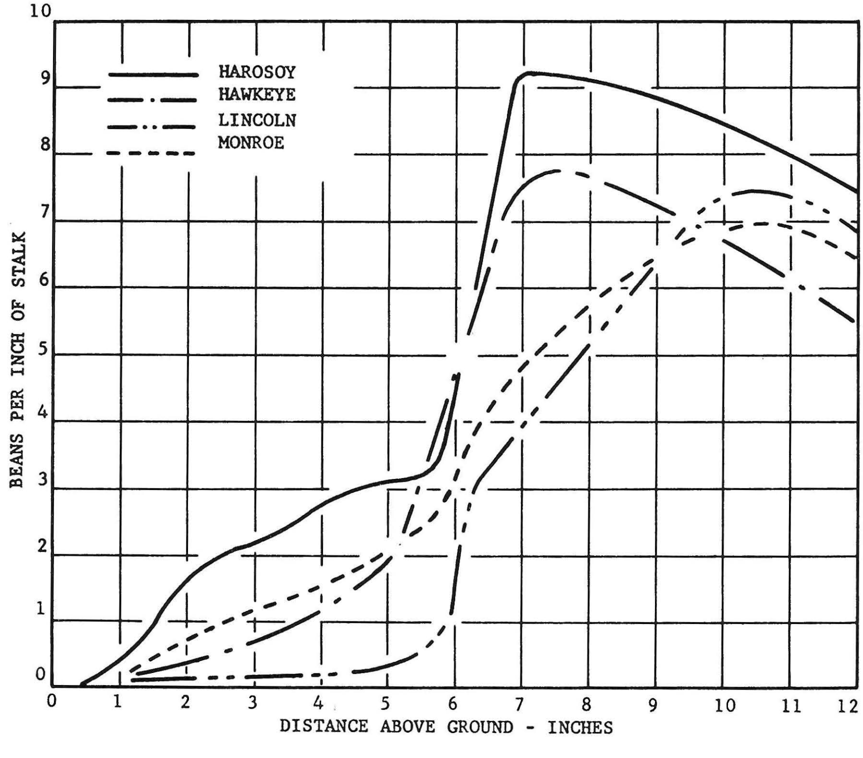


Fig. 11—Beans per inch of height of stalk for different varieties.

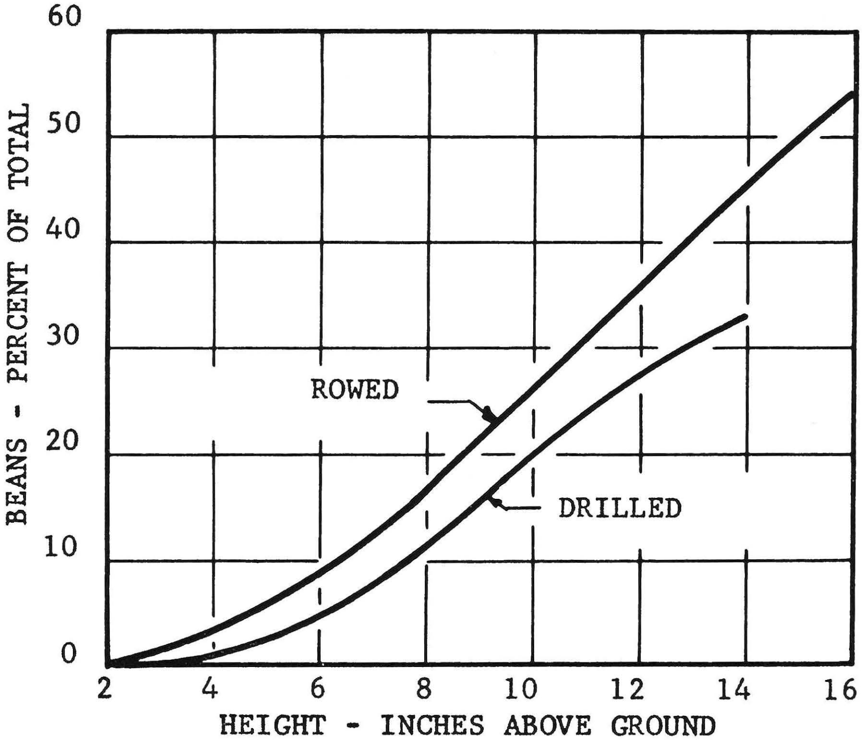


Fig. 12—Effect of planting method upon height of beans above ground.

Table 4.—Effect of Harvesting Ground Speed upon Losses (each datum is an average of 18 tests)

Item	Ground speed, mph 2.5	3.2	5.0
Shattered loss, pounds per acre	118	111	152
Stubble loss, "	38	61	109
Lodged loss, "	14	21	41
Stalk loss, "	21	22	26
Cylinder loss, "	6	7	7
Rack loss, "	7	7	8
Total loss, "	211	236	350
Shoe loss, "	7	6	6
Harvesting efficiency, percent	89.7	88.5	82.0
Stubble height, inches	6.4	7.3	9.3
Cutting index	0.55	0.43	0.27
Reel index	1.8	1.4	0.9

The reel axis should be adjusted so that it is 6 to 12 inches ahead of the knife. As long as stalk carry-over is not present, the adjustment had minimum effect upon losses within the scope of this study.

Ground speed has a very pronounced effect upon gathering losses. Typical results of varying ground speed without making any machine adjustment are presented in Table 4 and in Figure 16. Shattered loss

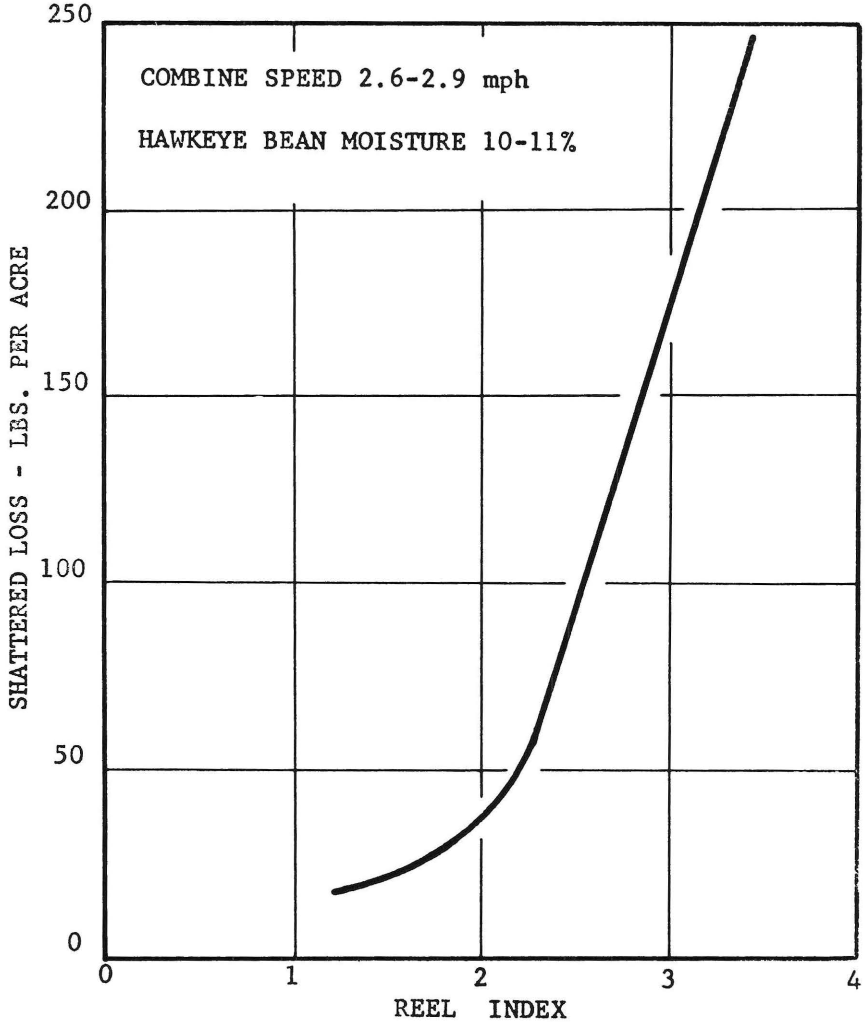


Fig. 13—Relationship between shattered loss and reel index.

increased at the extremes in speed (with power driven reels) because the reel rpm was too high at the lower ground speed and excessive stripping by the knife occured at the higher speeds. Stubble loss increased with speed because higher effective stubble heights resulted. Lodged loss increased because reel index became too low at the higher speed. Cylinder, rack and shoe losses were nearly independent of ground speed.

Design Choices Influencing Gathering Losses

Within the scope of this research, type of reel drive (power or ground drive) seemed less important to minimize gathering losses than did the ability to adjust the reel according to operating conditions.

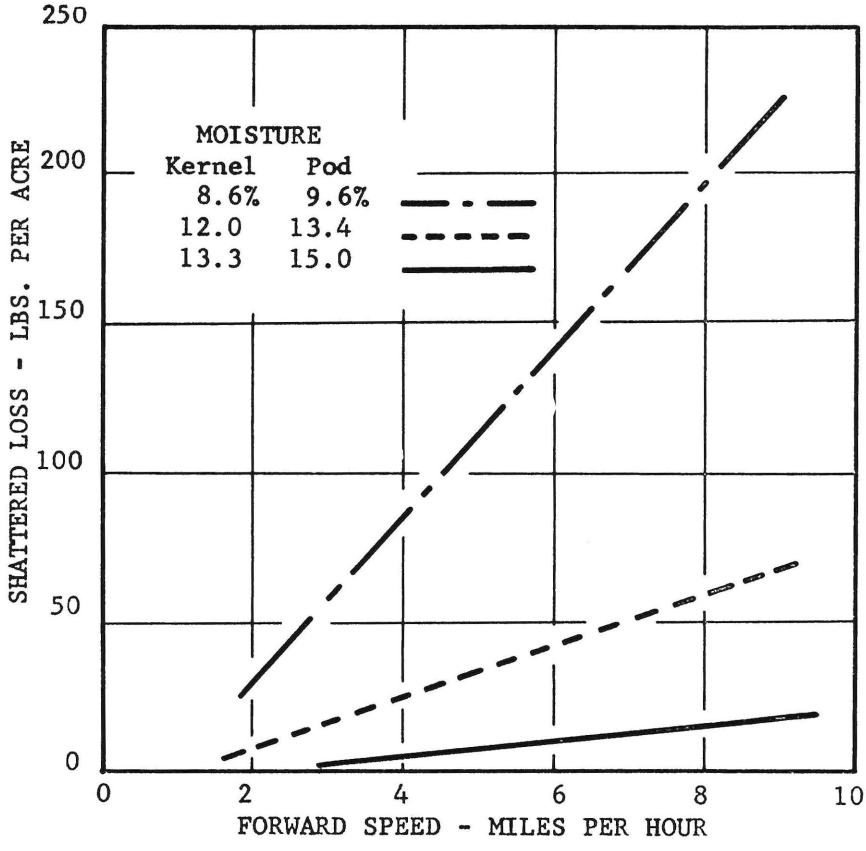


Fig. 14—Relationship between shattered loss and ground speed (ground driven reel).

Foremost, reel rpm should be easily adjustable so that favorable reel indexes and speeds can be obtained. The vertical height of the reel above the cutterbar should be readily adjustable also. Reels which cause minimum agitation during entry and which contact only a portion of the total grain will result in reduced gathering losses. Reel

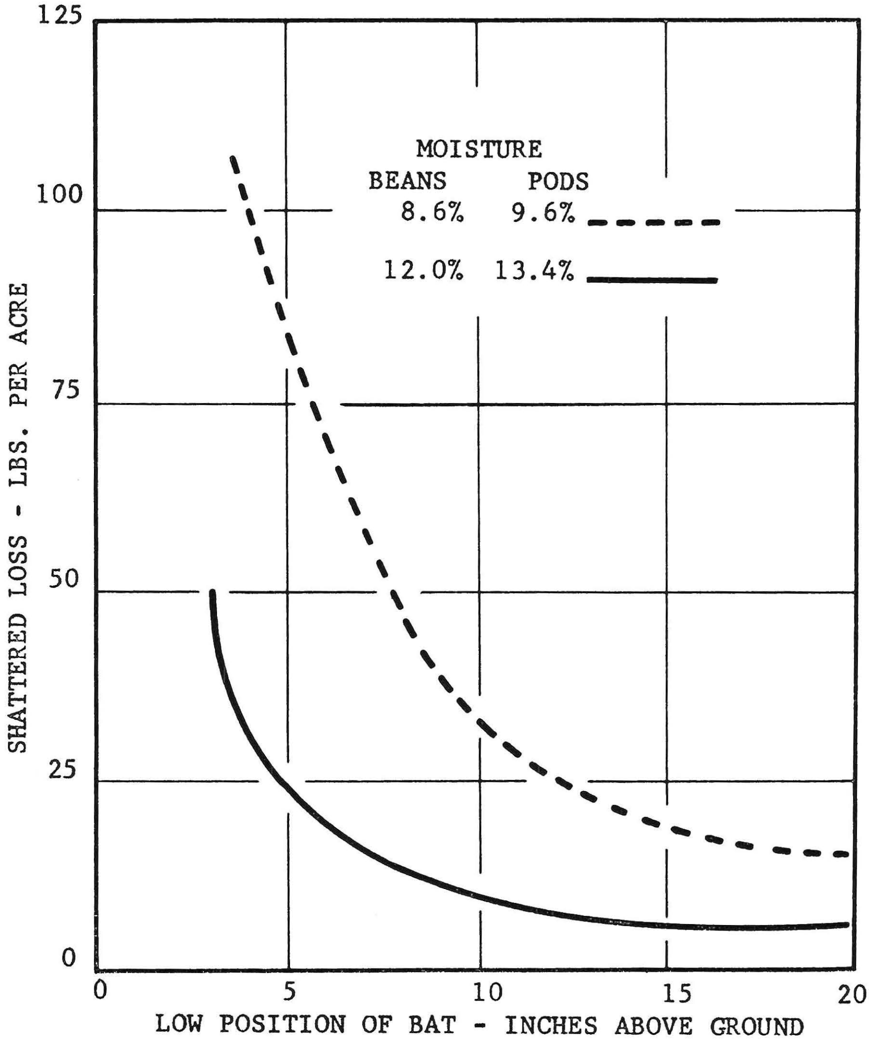


Fig. 15—Relationship between reel vertical adjustment and shattered loss.

diameter and range of reel adjustment were inadequate when operating under weedy crop conditions on some of the machines.

Gauging the height of the cutterbar above the ground is difficult, particularly when operating a self-propelled machine in lodged and/or weedy conditions. Devices which maintain a pre-set height resulted in improved efficiency, increased harvesting speeds and reduced operator fatigue. Up to five percent more beans were harvested per acre and under very adverse operating conditions (rough terrain, dense weed growth) ground speed was nearly 50 percent greater. A depth gauge to establish cutting heights would benefit many operators.

As width of cut increases the probability of greater gathering loss also increases. Average gathering losses were generally greater with the self-propelled ten-foot combines than with the seven-foot pull type combines. Greater flexibility within the header so that it can adapt to the ground contour would be beneficial in wider headers.

Preharvest shattered loss was determined at various dates during the harvesting season.

Date and Moisture at Harvesting

Five conditions of harvesting were selected during the 1956 season as follows: (1) high moisture harvesting in the 15 to 20 percent kernel range, (2) timely harvesting (harvest as soon as the grain was dried to 13 percent), (3) delayed harvest (two weeks after condition 2), (4)

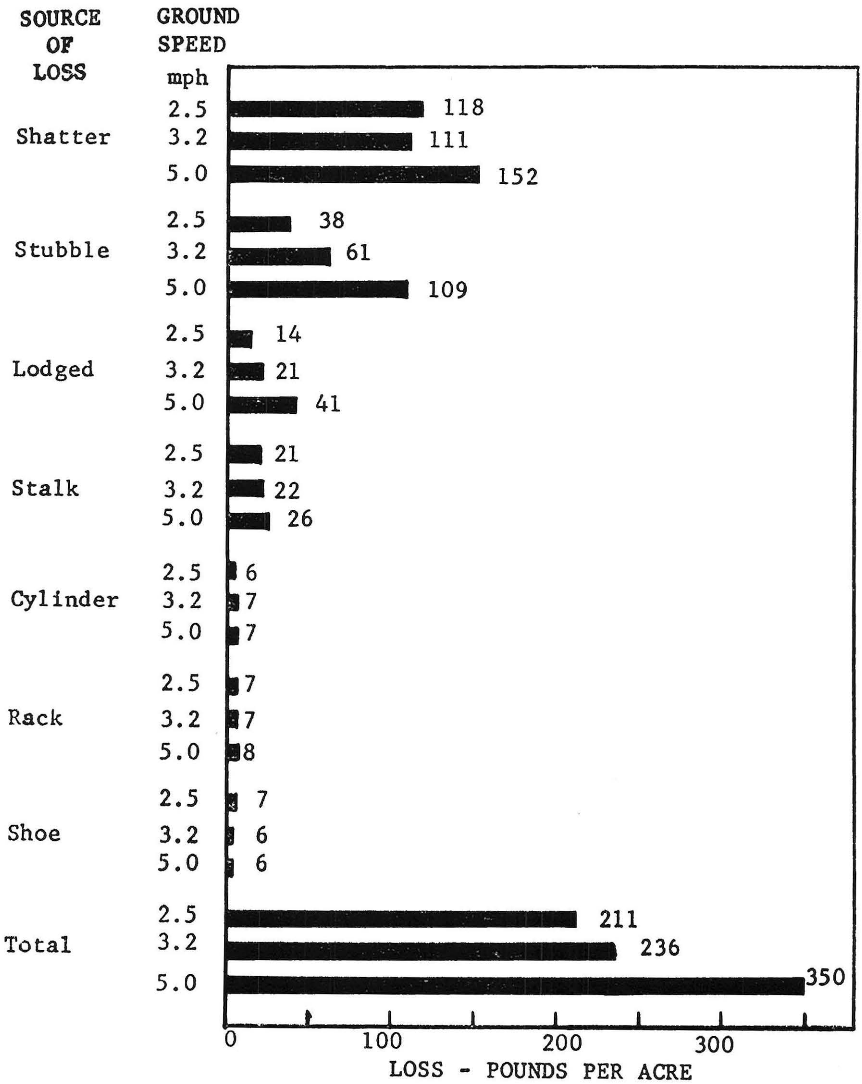


Fig. 16—Effect of ground speed upon harvesting losses.

harvest of rewetted grain and (5) extremely delayed harvesting of dry grain. These varying conditions permitted yield, test weight, germination and other comparisons. In addition, feasibility of high moisture harvesting was studied. Date of harvesting, crop conditions and machine data are presented in Table 5.

Table 5.—Date of Harvesting, Crop Conditions and Cylinder Adjustment Data for Five Conditions of Harvesting (Harosoy and Hawkeye Varieties)

	Harvesting Treatment				
Description	(1) High moisture	(2) Timely harvest	(3) Delayed harvest	(4) Rewetted from rain	(5) Extremely delayed harvest
Date of harvest	Sept. 27	Oct. 1	Oct. 12	Oct. 24	Nov. 3
Kernel moisture, percent	19.1	14.4	13.3	17.2	14.7
Straw moisture, percent	48.5	26.6	25.3	20.1	23.9
Combine used	A and B	A and B	A	A	A
Cylinder speed, fpm	3380	2600	2350	5300	3250
Concave clearance, inches	3/8	3/8	3/8	5/16-3/8	3/8

Losses by source and other data are presented in Table 6 and Figure 17 for the various harvesting treatments. All data were obtained with machine A. Shattered loss was reduced one half or more in treatment 4. Pods and straw were damp from the rain effects during this treatment, but surface moisture had evaporated. Stubble, stalk and lodged losses remained relatively uniform during the five treatments, although lodged losses were highest on the last harvest date.

Cylinder losses were higher than desired in treatments one and two. This was a result of inadequate cylinder speeds. The variation in kernel moisture was a contributing factor. On one test in treatment 1, the average moisture content of the unthreshed grain (cylinder loss) averaged 42 percent kernel moisture while the harvested grain averaged 18.2 percent. Beans averaging 13 percent moisture and following the maturation drying curve (normal drying from the green stage) will contain some green immature beans. See Figure 18 for typical kernel and stem moisture relationship during drying from maturation.

Rack and shoe losses were completely satisfactory on all harvesting dates (machine A).

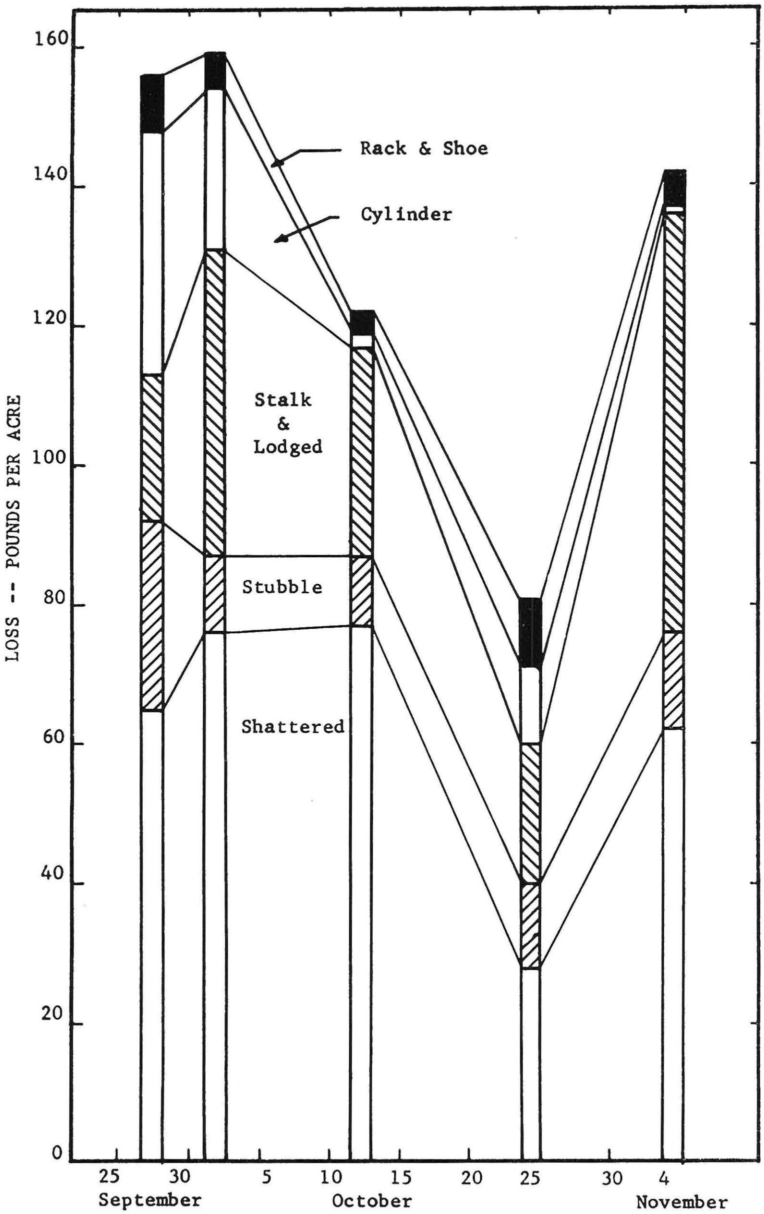


Fig. 17—Relationship between date of harvest and harvesting losses.

Table 6.—Losses by Source and Other Data by Harvesting Treatment (all values in pounds per acre or percent)

Item	Havesting_Treatment (1) High moisture	(2) Timely harvest	(3) Delayed harvest	(4) Rewetted from rain	(5) Extremely delayed harvest
Shattered loss	65	76	77	28	62
Stubble loss	27	11	10	12	14
Stalk and lodged loss	21	44	30	20	60
Total gathering loss	113	131	117	60	136
Cylinder loss	35	23	2	11	1
Rack loss	3	2	1	6	2
Shoe loss	5	3	2	4	4
Total loss	156	159	122	81	143
Harvested yield at 12 percent	1574	1609	1626	1587	1591
Crackage and splits, percent	4.8	2.7	2.5	4.2	15.3
Germination, percent	73.2	66.6	68.9	47.8	78.1

Soybean leaves begin to drop when the kernel moisture is above 40 percent. All leaves generally have shed before kernels are dried to 20 percent.

Samples of grain harvested at each date were analyzed for protein and oil content at the U. S. Regional Soybean Laboratory. There was less than three percent variation among the samples, indicating date of harvest did not greatly influence these properties. Protein and oil content, however, were lowest at the last date of harvest. (Percent protein was 38.3, 38.6, 38.7, 38.5 and 38.2 for the early through late harvest, respectively. Similarly oil content was 22.4, 22.7, 22.3, 22.6 and 22.0 percent.) Test weights also were lower on the last two dates of harvest, but the variation was less than two percent.

Germination drop with treatment four was very severe, indicating that harvesting under the rewetted conditions would not be advisable for seed grain. The drop was caused by the relatively high cylinder speed required to minimize cylinder loss. The amount of crackage and splits was satisfactory in all treatments, although the magnitude in treatment five indicated an excessive cylinder speed had been used. (Market beans are discounted when percent of splits exceeds 20 per cent.)

In Figure 19 harvesting efficiencies are plotted versus various dates of harvesting. Efficiency on the first two dates was lower than the

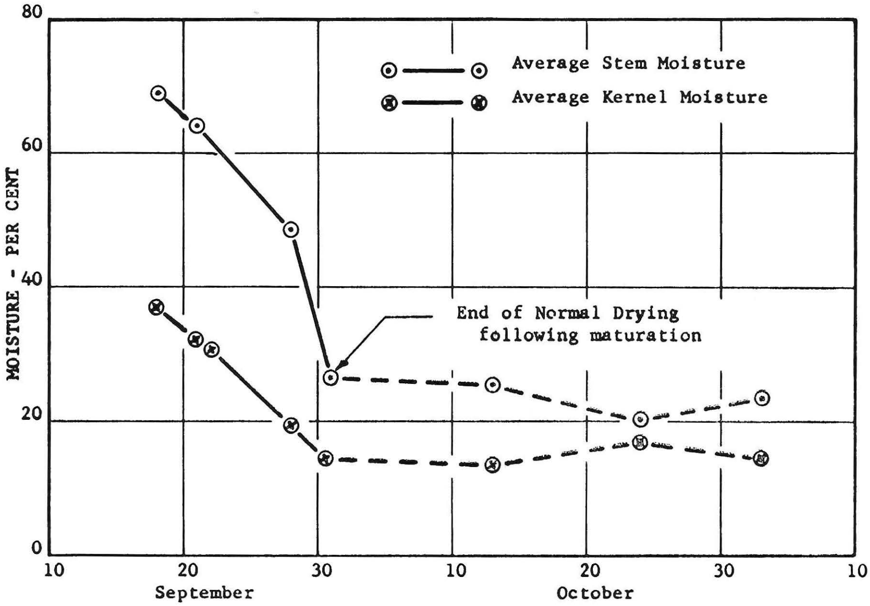


Fig. 18—Typical kernel and stem moisture relationship during drying.

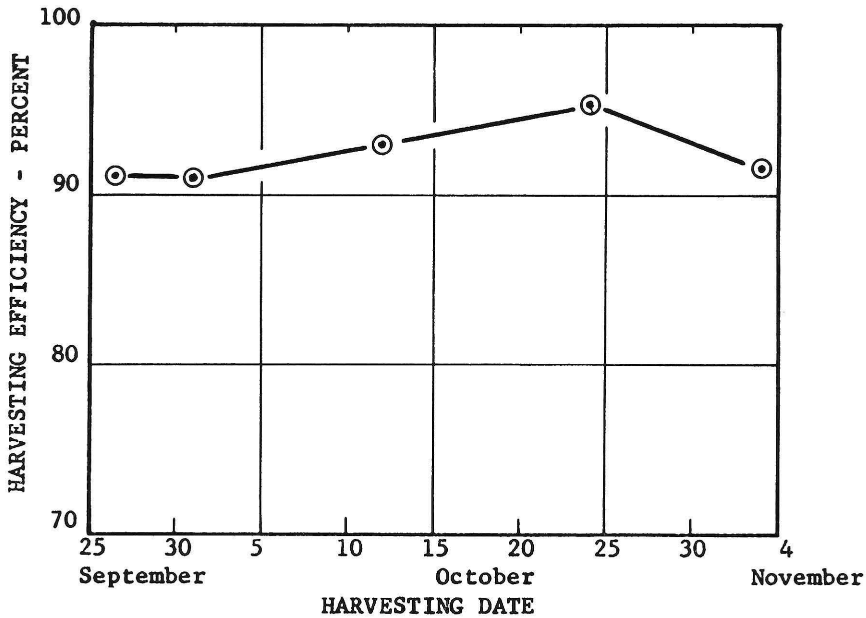


Fig. 19—Harvesting efficiencies at various harvesting dates.

others because cylinder loss was excessive. The highest observed efficiency was a result of harvesting under conditions when the beans were more difficult to shatter (stalks and pods damp from rain). Harvesting efficiency dropped in November because of an increased lodging loss. When pre-harvest losses are not a problem (when kernel moistures remain above ten percent) the harvested yield will remain constant when harvesting under dry straw conditions. By careful cylinder adjustment, harvesting efficiency on the two early dates could have equalled that of Oct. 15.

Hour of Harvesting

Harvesting when the stalks and pods were dampened from dew proved to be an effective method for reducing shattered losses. Beans were harvested during one day at three hours—7 a.m., 1 p.m. and 8 p.m. Results are presented in Figure 20. Total gathering losses were reduced by nearly one-half. Shattered loss was reduced by nearly one bushel per acre. Cylinder speed in the morning had to be nearly double that required in the afternoon to keep threshing losses reasonable. Rack and shoe losses increased slightly in the morning but remained under ten pounds per acre.

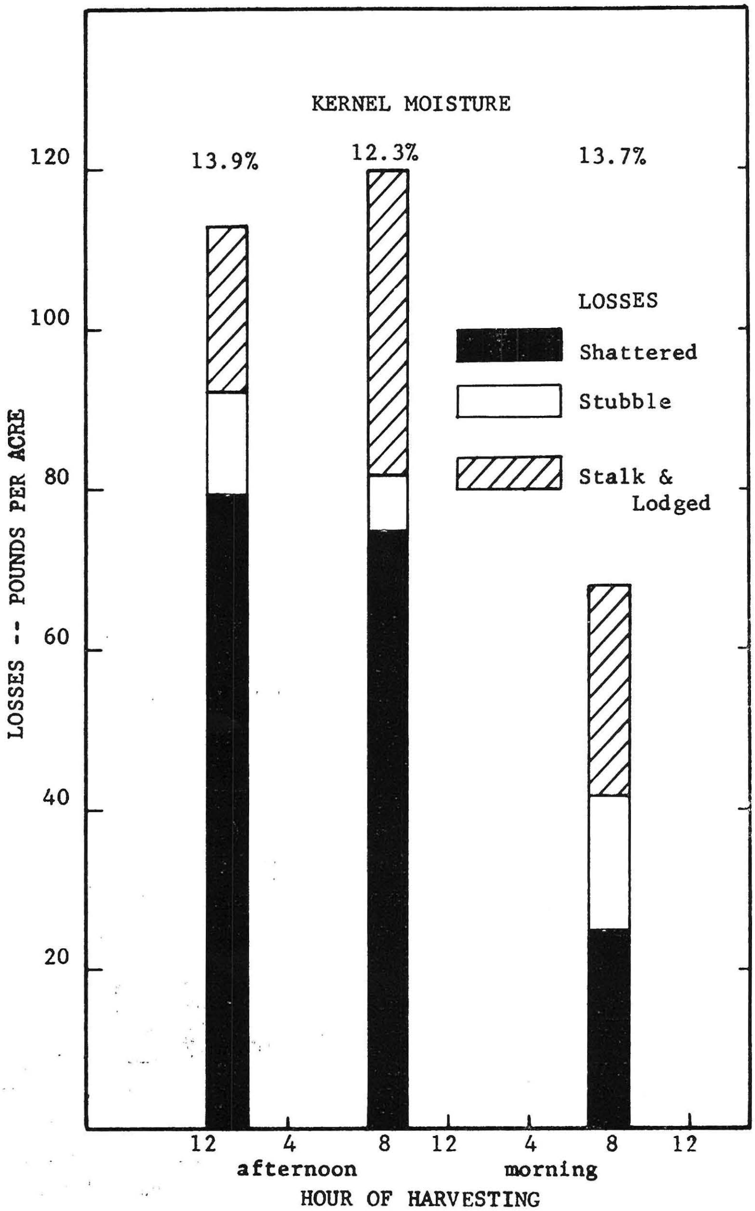


Fig. 20—Harvesting losses at 7 A.M., 1 P.M., and 8 P.M.

In Figure 21 shattered losses as a function of hour of harvesting are plotted. As the dew effects were diminished, shattered loss increased. Kernel moisture at the various hours is also shown. Other gathering losses were not influenced by the dew.

Cylinder Adjustment

It follows that if beans are more difficult to shatter when harvesting at higher pod moistures, they will be more difficult to thresh and higher cylinder speeds or closer clearances would be required.

Changes in cylinder speed have a much greater influence upon cylinder losses, germination and crackage than do changes in cylinder-concave clearances. For acceptable performance, changes in clearance alone would be inadequate for morning and afternoon harvesting. The information in Table 7 is presented to show the need for frequent adjustment of the threshing effort when operating under changing pod moisture conditions. Rapid methods for changing cylinder speed need to be designed into the harvester.

Beans lying on the ground were defined as shattered loss. Beans remaining in pods on stubble were stubble loss.

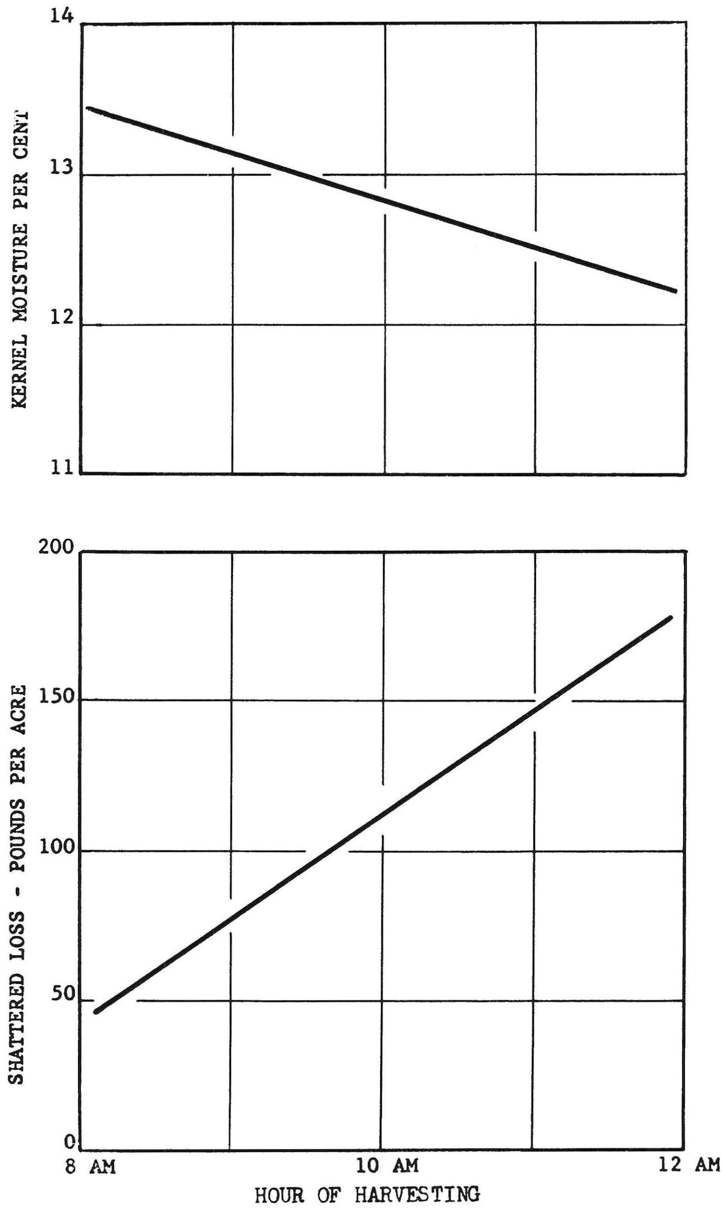


Fig. 21—Effect of hour of harvesting upon shattered loss and kernel moisture.

Table 7.—Comparative Cylinder Losses When Operating With Same Cylinder Adjustment During Morning and Afternoon Hours

Bean Condition	Cylinder Adjustment	Item	Harvested A.M.	Harvested P.M.
Early season, crop on normal drying cycle.	4480 fpm, minimum clearance, 1/4-5/16″	Kernel moisture, percent	6.5	24.7
		Cylinder loss, pounds per acre	13	1
		Kernel damage, percent	19.1	16.0
Mid season, drying after rain.	2420 fpm, minimum clearance 1/4-5/16″	Kernel moisture, percent	16.3	12.6
		Cylinder loss, pounds per acre	144	2
Mid season, heavy dew.	2350 fpm, clearance 3/8″	Kernel moisture, percent	13.7	12.3
		Cylinder loss, pounds per acre	201	2

The relationship of cylinder speed to cylinder loss, germination and crackage is presented in Figure 22 for high moisture harvesting. Cylinder speeds of at least 4500 fpm were required to keep cylinder loss at an acceptable level under high moisture harvesting conditions. Crackage was under that which would result in a marketing penalty. Increased speed depressed germination; however, other factors such as procedures used to store high moisture beans influence it also. Germination figures are based upon whole, undamaged beans. If based upon the total sample, the germination values would be lower by the amount of crackage.

Miscellaneous Results

Variety effect upon harvesting losses—In Figure 23, the magnitudes of various sources of losses are presented for four varieties. Combine B was used with cylinder speed of 2300 rpm and 3/8 inch clearance. Additional comparisons among the varieties are made in Table 8.

Whole bean stalks still attached were defined as lodged loss.

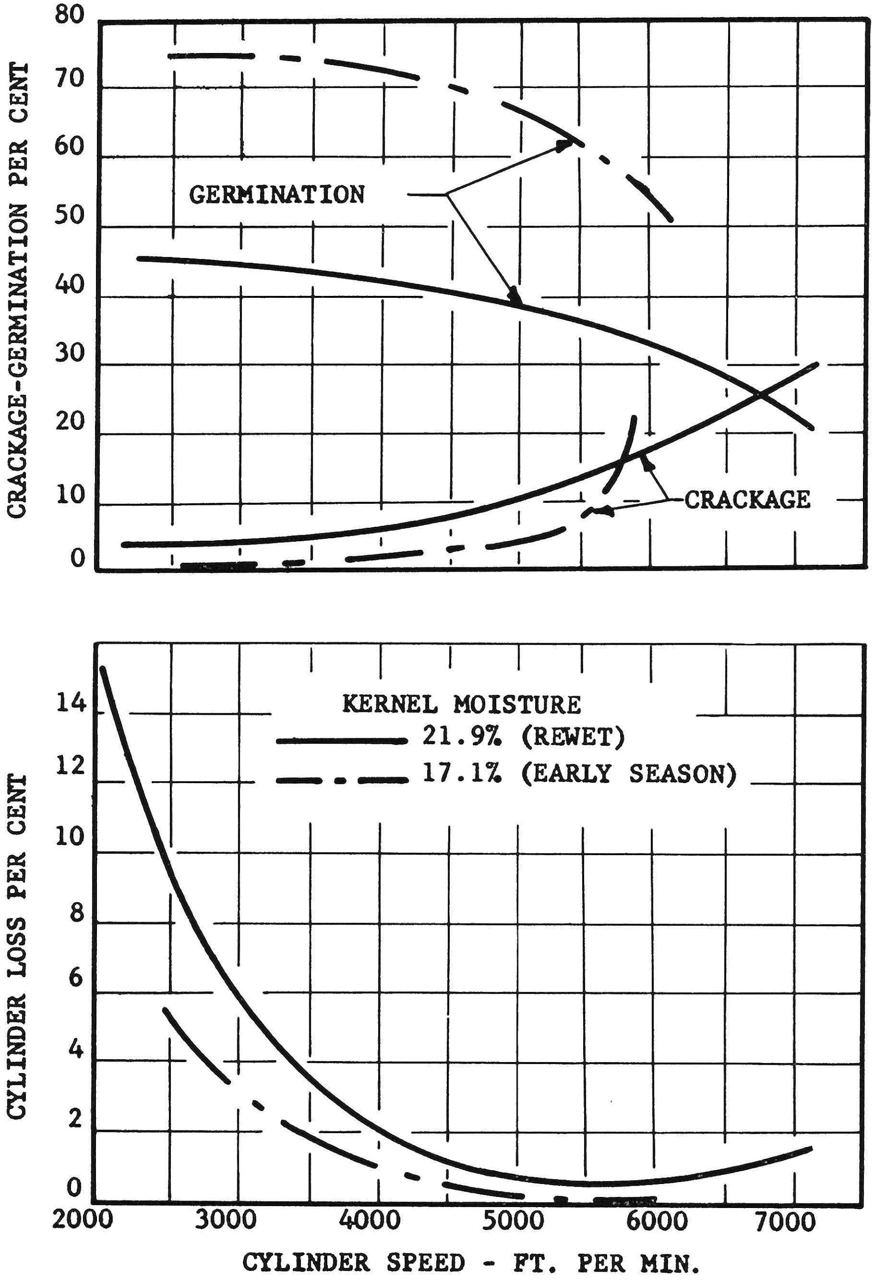


Fig. 22—Relationship of cylinder speed to cylinder loss, germination and crackage.

Except for shattered and stubble losses, harvestability differences among the varieties are minor. The relative magnitude of shattered and stubble losses are those predictable from height-of-set curves (Figures 10 and 11). Harvesting efficiency was much lower for the Harosoy variety because of the large gathering loss.

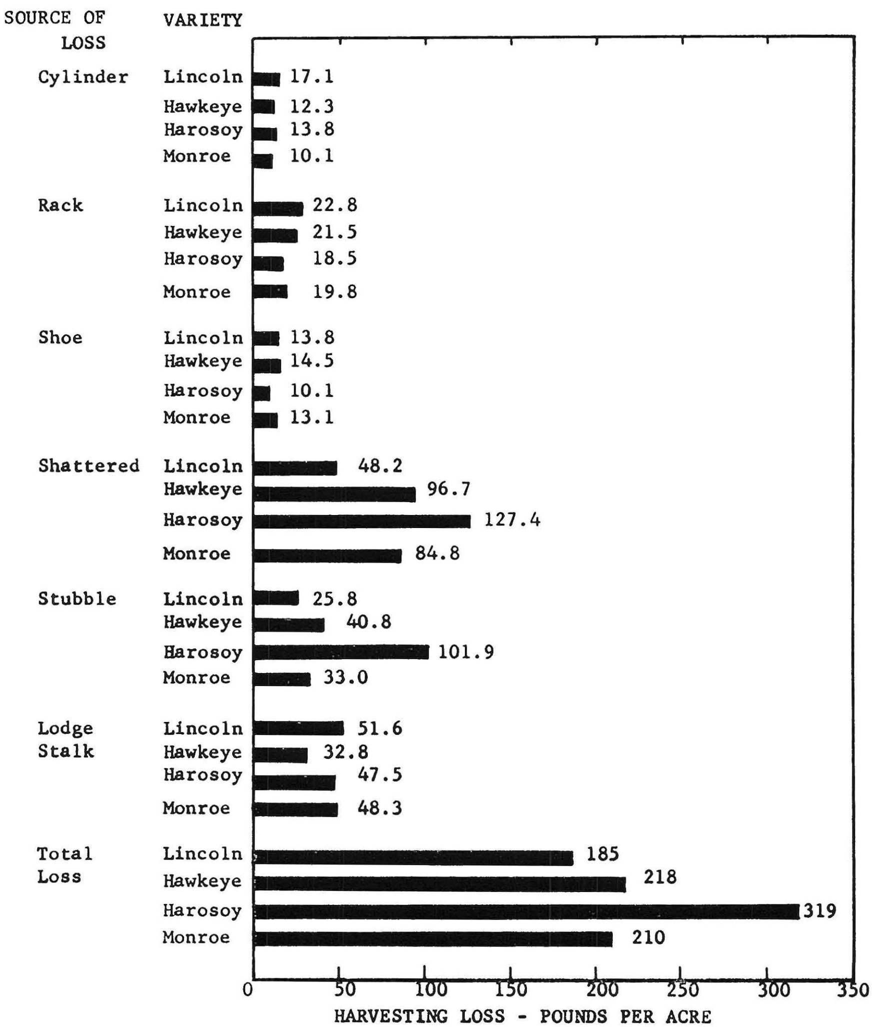


Fig. 23—Losses by source for several varieties.

Table 8.—Comparative Results With Varieties

Item	Variety			
	Lincoln	Hawkeye	Harosoy	Monroe
Kernel moisture, percent	9.8	9.8	10.0	10.0
Tank yield, pounds per acre	1,639	1,543	1,607	1,450
Harvesting efficiency, percent	89.6	87.6	83.5	87.3
Crackage, percent	8.6	5.6	9.0	7.3
Germination, percent	73.8	73.0	65.5	68.7
Kernels per 60 pound bushel	182,500	147,500	154,000	183,000
Rack load, pounds per acre	1,350	1,000	1,400	1,130
Shoe load, pounds per acre	480	450	500	430
Straw/grain ratio	1.00	0.82	0.99	0.94

Foreign Material in Grain Tank

Harvesting soybeans which are badly infested with weeds offers a major cleaning challenge, if harvesting is done before the weeds die. Cleaning shoes which screen over and under size would do an excellent job of removing the undesirable debris. Combine B was equipped with a separate recleaner which permitted the smaller sized weed seeds to be screened from the grain. In Figure 24, the effectiveness of the recleaner in rowed and drilled beans is shown.

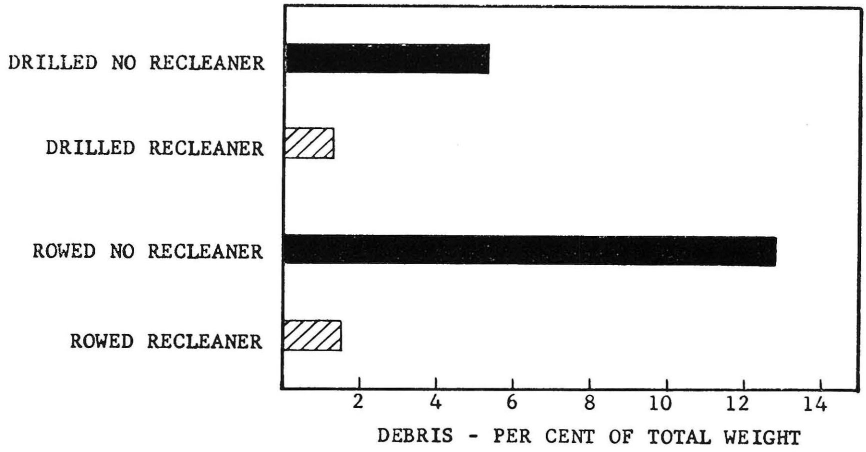


Fig. 24—Effectiveness of seed recleaner for removing weed seeds and debris.

Tailings Load

Investigation of the tailings can suggest information concerning the performance of the cleaning components of a harvester. The effect of cylinder speed upon rack, shoe and tailings load is presented in Figure 25. As to be expected, shoe load increased with increasing cylinder speed. Tailings discharge also increased, but the composition of the tailings remained about the same. Seventy percent was completely threshed beans; 29.2 percent bean-free-pods and other debris; and 0.1 percent unthreshed beans in pods. Kernel moisture varied from 12.2 to 13.1 during the tests; rack and shoe losses in all tests were less than ten pounds per acre.

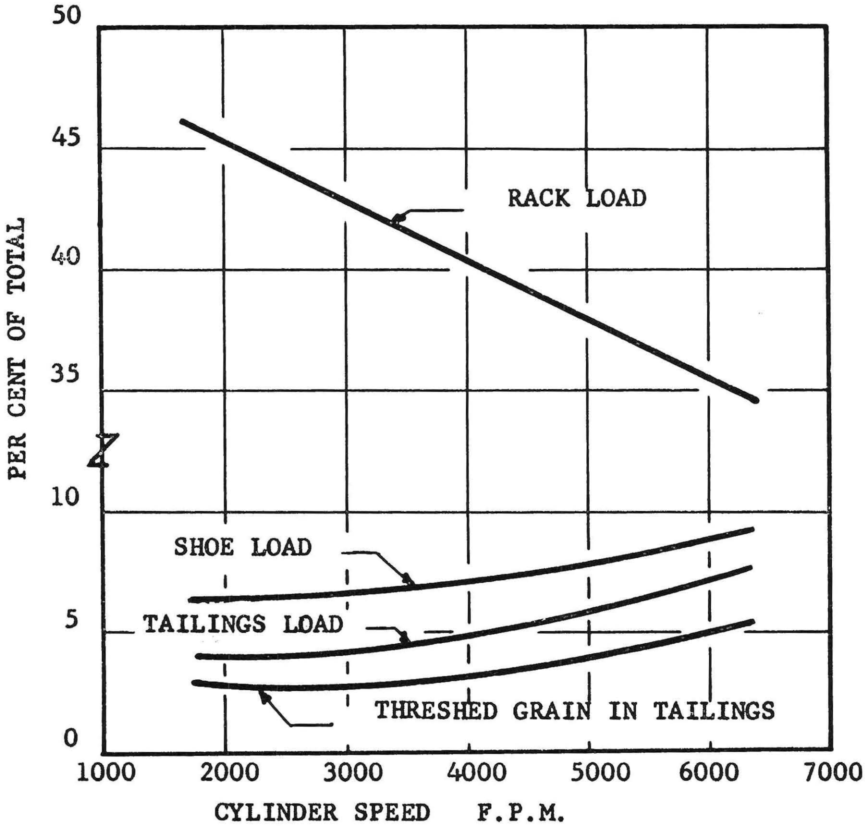


Fig. 25—Effect of cylinder speed upon rack, shoe and tailings load.

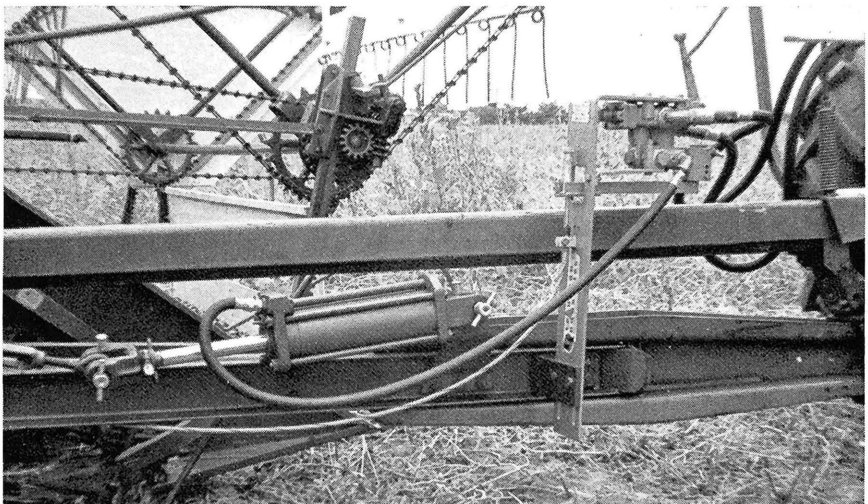
Tests with ground speed and concave clearance as variables also resulted in total unthreshed grain in the tailings of less than one percent of tailings weight (less than 0.10 percent of tank yield). A typical division of materials entering a harvester is shown in Figure 26.

The inherent purpose of the tailings assembly is to return to the cylinder mechanism any unthreshed grain. In soybean harvesting, the need for the tailings assembly can be questioned.

Experimental Reel

Minimum agitation and contact during entry, definite rearward movement relative to the grain after entry and capacity to discharge the gathered grain after cutting are desirable qualities of a reel. It was reasoned minimum agitation would result when the motion of the bat was perpendicular to the ground during entry and parallel travel to the ground during the rearward movement would be desirable for pick-up. These motions can not be achieved with a conventional circular reel.

An experimental reel was designed and installed for evaluation of the concepts. Bats followed a triangular path which gave the desired motion. A ground drive was used so that the perpendicular motion



This combine is equipped with an experimental reel and a device for maintaining a constant cutterbar height.

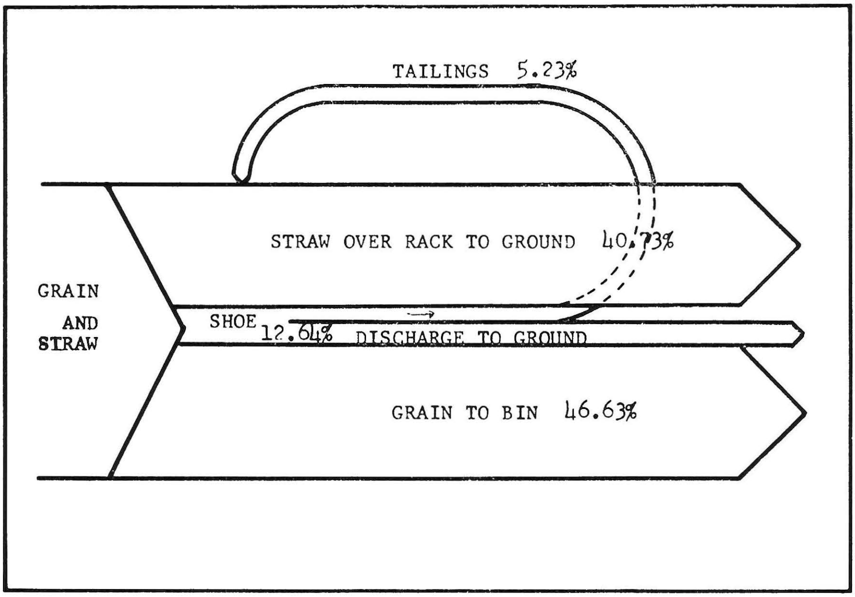


Fig. 26—Typical division of materials flowing through combine.

during entry could be obtained. Tines were attached to the bat so that minimum contact with down grain would occur.

Mechanical problems, resulting from excessive inertia forces, limited field trials and evaluation of the concept. Redesign with weight reduction and perhaps other means of achieving the motion would partially, if not completely, solve the mechanical problems. The limited experience under field conditions of the concept indicated definite value when the crop was readily susceptible to shattering.

Variable Knife Speed

Several exploratory tests were conducted at knife speeds 50 to 150 percent of designed knife speed. All other conditions were maintained constant. No consistent trends were evident. Under the conditions of the tests, the design knife speed gave the best results. It was not possible to eliminate the effect of the reel in these tests, which may help to explain the result. The strength of the knife assembly was inadequate for the higher speed and considerable vibration existed.

Rowed Versus Drilled Method of Planting

Experimental design was not intended to return yield and other comparisons between the rowed and drilled methods of planting. However, during the five years of the research some general observations were recorded. Although rowed and drilled beans were planted in adjacent field strips, fertility and other differences could have caused the variations.

All discharges were weighed prior to retheshing.

During every year except 1958 the drilled beans out-yielded the rowed beans by 10 to 21 percent. During the late, wet 1958 season, the rowed beans out-yielded the drilled beans by approximately 40 percent. Yield comparisons were not made in 1960. Heavy weed growth existed in the drilled beans during the 1958 and 1960 seasons. Also, the rows were only 30 inches apart during the 1958 season compared to 40 inch spacing other years.

Gathering losses were higher for rowed beans, particularly stubble loss. This is as expected from the height of set curves (Figure 12). Cylinder, rack and shoe losses were not influenced by planting method, since rack and shoe capacities were adequate for all machines.

Drying High-Moisture Beans

During this research, specific studies concerning the requirements for drying of high moisture beans were not attempted. Facilities ade-

Cutterbar losses were predicted from within a fixed area following the machine.

Table 9.—Relative Penalties When Marketing Beans at Various Moistures and the Increase in Harvesting Efficiency Necessary to Offset the Moisture Discount Cost.

Moisture percent	Actual value per bushel*		Market price per bushel**		Net cost of moisture***		Yield increase required to offset, in bushels	
	$2.00	$2.50	$2.00	$2.50	$2.00	$2.50	$2.00	$2.50
16	$1.931	$2.414	$1.85	$2.35	$0.081	$0.064	1.31	0.81
15	1.954	2.443	1.90	2.40	0.054	0.043	0.85	0.53
14	1.974	2.471	1.95	2.45	0.024	0.021	0.37	0.25
13	2.000	2.500	2.00	2.50	0	0	0	0
12	2.023	2.529	2.00	2.50	0.023	0.029	0.35	0.35
11	2.046	2.557	2.00	2.50	0.046	0.057	0.69	0.68
10	2.069	2.586	2.00	2.50	0.069	0.086	1.03	1.03
9	2.092	2.615	2.00	2.50	0.092	0.115	1.38	1.38
8	2.115	2.644	2.00	2.50	0.115	0.144	1.73	1.73

*Determined by multipling $\frac{\text{pounds dry matter at any moisture}}{\text{pounds dry matter at 13 percent}}$ by market price.

**Based upon 2½¢ per bushel discount per one-half percent moisture above 13 percent.

***Difference between actual value and market price.

quate for drying wheat and other grains will be satisfactory for drying soybeans. Forced, unheated air was used to condition beans harvested at 18 to 19 percent. Generally, over night conditioning was sufficient to reduce the moisture to market level.

CONCLUSIONS, APPLICATIONS OF RESEARCH, and RECOMMENDATIONS

1. Gathering loss will be over eighty percent of total harvesting losses for a properly adjusted machine. Of the gathering loss, shattered losses will generally be the largest loss when harvesting grain 13 percent kernel moisture and under.

2. Ease of shattering depends upon the moisture content of the pod, increasing as the moisture decreases. Preharvest shattered loss becomes a major source of loss when kernel moisture drops below 10 percent.

3. Harvesting when the plant has been rewetted by dew or rain can prove to be an effective way to improve harvesting efficiency.

Rack and shoe discharges were caught in canvases. Tailings discharge was caught at the auger.

a. Cylinder speed will need to be increased to nearly twice the recommended speed for dry beans.
b. Germination of grain harvested with high cylinder speeds will be inferior to that threshed at normal speeds.
c. Early season harvesting of high moisture beans is complicated by variability in kernel moisture and green residues.

4. In adjusting and operating a combine-harvester,
   a. Bat speed of the reel should be nearly 1.25 times ground speed.
   b. Bat should penetrate no deeper than required to control the grain. The reel center line should generally be 6 to 12 inches ahead of the cutterbar.
   c. A cylinder speed should be selected which completely threshes all beans (ten pounds of loss per acre). Rack and shoe losses will generally be acceptable.
   d. Maintain a ground speed which permits the reel index to be 1.25 and the cutting index over 0.50.
   e. For weedy conditions, consider a recleaner.

Combines equipped with seed recleaners are necessary to remove green material when harvesting a weedy crop.

In application of the research results, separate recommendations are made to the farmer-operator, to the engineer-designer and to the plant breeder-agronomist, since each has a different responsibility and contribution toward the goal of improved harvesting efficiency.

Farmer - Operator

1. High moisture combining will offer the following advantages when the harvester is adjusted properly:

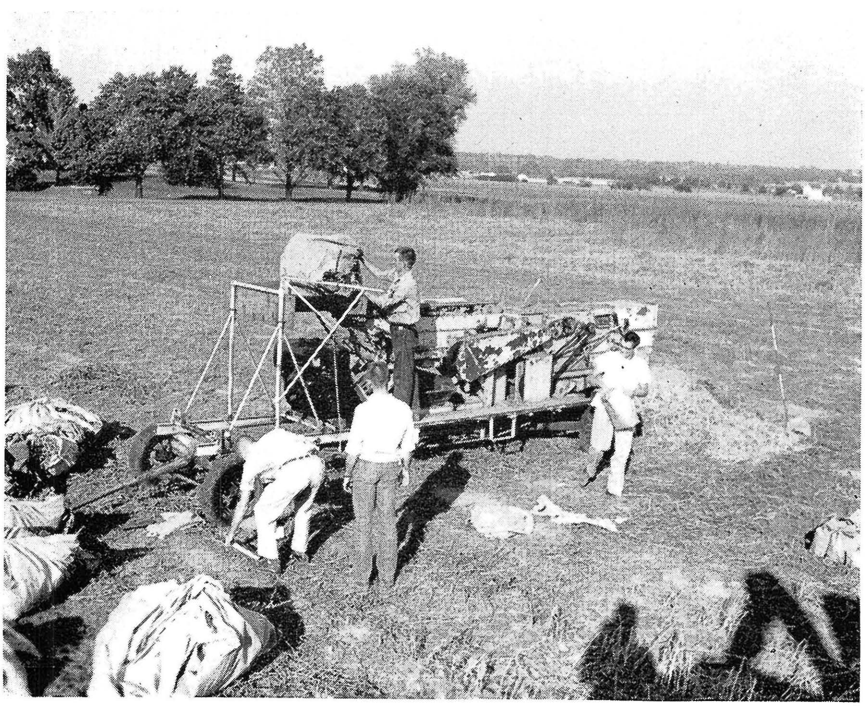
   a. Reduced harvesting losses.

   b. Increased acres per machine by harvesting during more hours per day.

   c. More timely harvesting and reduced competition with other farm work.

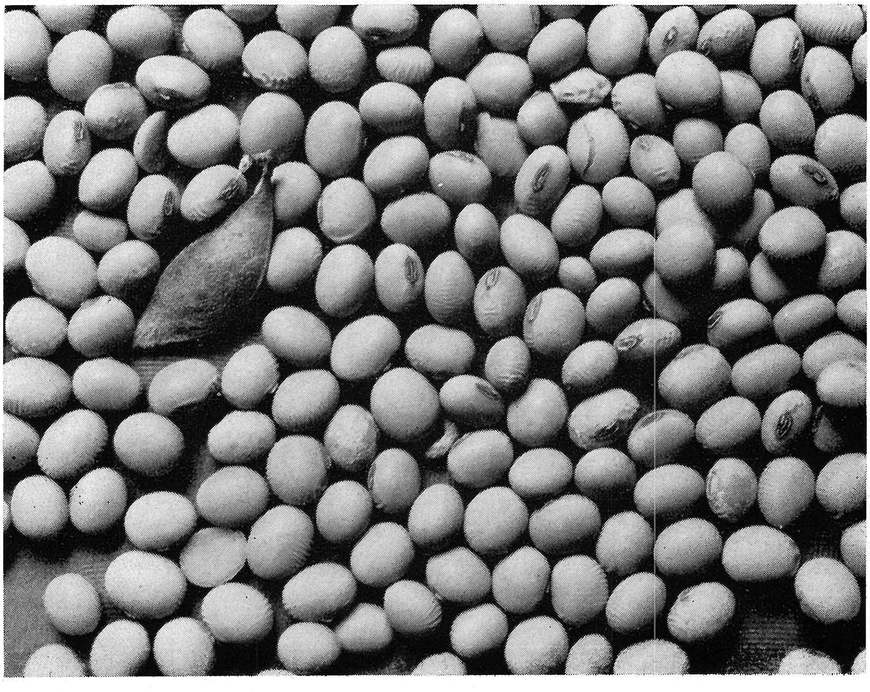
   d. Eliminate loss occurred in marketing when over-dry beans are sold.

   e. Crackage and splits can be better controlled.



Rethresher crew is determining rack and shoe losses.

Cylinder speeds adequate to keep threshing loss low in the morning will cause excessive bean damage in the afternoon.



2. High moisture combining will cause the following possible disadvantages:

a. Increased cylinder losses if harvester is not properly adjusted.
b. More frequent adjustment of the cylinder required.
c. Reduction in germination.
d. Possibly require drying facilities.

3. Concepts in equipping, adjusting and operating a harvester for soybean harvesting are different from those in harvesting wheat and other small grains in the following ways:

a. Maintenance of a constant ground speed that yields a desirable reel and cutting index is important in soybean harvesting. (Soybeans are subject to greater shattering loss and to stubble loss).
b. Cylinder adjustment should be to finalize threshing, since rack and shoe losses will be generally insignificant for the properly adjusted machine.
c. Equipping the combine with hydraulic and other mechanisms to permit easy and accurate height adjustment and control is important for minimum losses.
d. A recleaner will be a desirable attachment during many seasons when weed infestation is severe.

4. Efficient harvesting depends in part upon decisions and practices followed by the farmer during planting and cultivation of the crop. Weeds should be avoided and ridging of the rows minimized. Select varieties not only according to potential yield but also to probable tank yield and harvesting date.

There is great resistance to the acceptance of marketing penalties for high moisture grain by farmers. However, the penalty for marketing over-dry beans is generally greater than the discounts from high moisture grain. Table 8 has been prepared to show the relative costs when marketing beans at various moistures. The table also indicates the increase in yield required to offset the moisture discount cost. The careful operator can generally offset any moisture discount by increased yield through high moisture harvesting. There is no possibility of offsetting the loss when the beans are over-dry.

1. Devices which permit maintenance of adequate and proper cutterbar height under all conditions would improve harvesting efficiency, reduce operator fatigue and possibly reduce repair costs. Automatic header controls and devices for gauging the height of cut should be considered.

2. Increased emphasis should be given to gathering components. Areas of concern should be:

a. Improved reels, offering either minimum agitation for standing crops or positive pickup action for lodged crops.

b. Convenient, "on the go", height adjustment between the reel and the cutterbar would offer functional benefits in fields with lodged and standing crop.

c. More adequate means for adjusting reel speed would contribute to improved harvesting efficiency on some machines.

d. Higher cutting indexes for faster rates of travel would be beneficial.

e. Over-aggressive handling of the cut material following cutting by the knife results in threshing and losses on some machines.

f. Reel diameters on some machines are marginal (too small) for tall beans and weedy conditions. The range of adjustment is inadequate.

3. Rapid-change devices for adjusting cylinder speeds is a requirement for successful high moisture combining.

4. The contribution which the tailings assembly makes to machine functioning should be carefully evaluated.

5. The possible contribution which an under sizing screen could make as a part of the shoe should be studied for use in weedy conditions.

Plant Breeder and Agronomist

Varieties that have fewer pods near the ground and are lodge resistant are desirable in harvesting. In addition, the following comments are offered:

1. Evaluation of varieties should include a mechanical shattering test. The designer could use more aggressive gathering components with varieties that are difficult to shatter.

2. Greater uniformity in kernel moisture would be a desirable goal. Early season high moisture harvesting would probably be feasible if attained.

3. There are indications harvesting of drilled beans would result in improved harvesting efficiencies, if weeds could be controlled.

DEFINITIONS

1. $$\text{Method efficiency} = \frac{\text{harvested yield}}{\text{potential yield}} \times 100$$

2. $$\text{Machine efficiency} = \frac{\text{harvested yield} + \text{machine losses}}{\text{harvested yield}} \times 100$$

3. Potential yield = preharvest loss + harvested yield + machine losses

4. Preharvest loss = beans detached from stalks and lying on the ground prior to harvesting

5. Machine losses = gathering (header or cutterbar) loss + cylinder (threshing) loss + rack (separation) loss + shoe (cleaning) loss

6. Gathering loss = shattered loss + stubble loss + lodged loss + stalk loss
    a. shattered loss = beans free of pods or in pods free of stalk
    b. stubble loss = beans remaining in pods attached to the stubble
    c. lodged loss = beans remaining in pods attached to stalks which were not cut or were cut at lengths greater than the stubble
    d. stalk loss = beans remaining in pods attached to stalks which were cut but not delivered into the harvester

7. Cylinder loss = unthreshed beans remaining in pods which passed through the harvester

8. Rack loss = beans free of pods which were discharged over the straw rack

9. Shoe loss = beans free of pods which were discharged over the shoe

10. Percent germination = number of strong sprouts obtained from 100 whole beans

11. Visual damage = percent splits and cracks by weight

12. Cutting index = depth of cut (number of strokes per minute times section cutting depth) divided by harvester forward speed

13. Reel index = bat peripheral speed divided by harvester forward speed

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SUMMARY

Results of five years of research directed to improved soybean harvesting efficiencies are reported. Date of harvest, variety, machine adjustment and operation, hour of harvesting, design changes, planting method and other variables were studied for effect upon harvesting efficiency.

Proper adjustment and operation are required for satisfactory performance; even then, the harvesting efficiency will generally not be over 90-92 percent.

Principal source of loss was found to be gathering loss. Shattered loss was the largest individual loss. Cylinder, rack and shoe losses were generally very acceptable.

High moisture combining (when kernels are above 12 percent moisture and the pods are dampened from dew or rain) resulted in reduced shattered losses and an overall improvement in harvesting efficiency. Cylinder speeds had to be increased to insure complete threshing. Germination was depressed when high cylinder speeds were required.

Design changes in the gathering components of the machine are suggested which are more cognizant of the unique characteristics of the soybean. Suggestions are made to the plant breeder and agronomist for changes which would contribute to higher harvesting efficiencies.

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